Weather Forecasting Services for the Canadian Offshore

Prepared for

The Royal Commission
on the
Ocean Ranger Marine Disaster

By

Donald O. Hodgins, Ph.D., P.Eng.
and
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SUMMARY

It is self-evident that many aspects of offshore exploratory drilling for oil and gas are affected by weather, and that from time-to-time human safety is threatened by adverse weather at sea. It is logical, then, to inquire into how the forecasting of severe weather is carried out in Canada, as it relates to offshore exploration, and how and what information is provided to operators so that they may take actions appropriate to ensuring safety. This report describes weather forecasting services in Canada and traces the flow of information through the Atmospheric Environment Service to the private forecast firms with whom the operators deal on a daily basis. It also discusses some important aspects of data acquisition, and describes a number of severe weather conditions which present difficulty to forecast services. Forecast preparation and presentation are reviewed, together with verification procedures used by various agencies. Conclusions are presented on forecast content, presentation and verification. The question of forecast adequacy is discussed in terms of the information level of forecast presentations and in terms of the relevance of information that is, or could be, presented to the offshore user.

The present study concentrated on forecasting services and the data disseminated by them to the end-user, the offshore operator. The terms of reference did not include a study of how forecast data are used by operators, at the shore base or on the drilling unit, to arrive at decisions affecting rig activities at sea. The affect of this on an assessment of adequacy of forecast data for ensuring human safety is discussed, and recommendations are given for examining this side of the question.

Traditionally the Atmospheric Environment Service (AES) has been responsible for weather forecasting throughout Canada. Marine and aviation forecasts fell under their jurisdiction in addition to forecasts for general public use. Under regulation of

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offshore drilling, first by the Department of Energy, Mines and Resources, and later by the Canada Oil and Gas Lands Administration (COGLA), operators were required to contract location- and route-specific weather forecast services. In the Eastern Canadian offshore these services were provided by private corporations catering specifically to this need. Again by regulation, these firms had to have personnel trained by the AES or to AES standards. Because of this, and the central, dominate role played by the AES, a strongly hierarchial, and in many respects redundant forecast service has evolved.

We have found that all of the groups involved in forecasting are tightly linked, especially at the level of the AES regional weather offices and the private forecast firms, because prognoses are based on the same cascade of information from within the organization, and because weather forecasting is approached using the same meteorological principles and equipment. One apparent consequence of this parallelism in public and private forecasting groups is a profound similarity in the preparation and presentation of forecast material. As a result there are no significantly different forms of data presentation available to offshore operators despite the apparently different sources to which they could turn in severe weather situations.

We have also found the level of information presented in forecasts to be extremely low judged against what could be done if full advantage were taken of electronic data processing, transmission and display facilities now available. Several causes were identified:

i) close adherence to traditional procedures and formats developed largely for lay-public consumption,

ii) use of simple, meteorological parameters to represent complex atmospheric and sea state conditions at a rig location, giving little or no indication of spatial variations to be expected, and

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i) close adherence to traditional procedures and formats developed largely for lay-public consumption,

ii) use of simple, meteorological parameters to represent complex atmospheric and sea state conditions at a site location, giving little or no indication of spatial variations to be expected, and

iii) the generally low accuracy of individual parameter values in terms of what one normally associates with engineering criteria for rig operations.

One is also led to question the relevance of some forecast information since it deals exclusively with atmospheric or wave height/period parameters. For decisions affecting drilling operations -- downhole activities, resupply, extreme rig behaviour for normal and abnormal circumstances -- that may have to be made by non-specialists in meteorology and oceanography, prognostic information on, for example, rig or supply boat motion response or crane derating values may be much more useful than traditional forecast parameters.

There is evidence to suggest that many dangerous situations which arise at sea are associated with what are termed mesoscale phenomena. These are weather features that form and move so rapidly, and which have such small dimensions, that they are not incorporated into synoptic scale forecasts. There are two contributing factors to this: first, mesoscale events generally escape observation and hence do not enter formally into the analysis and prognostic procedures, and second, the physics governing their formation and interaction with larger scale systems is not well enough undersoood to make them forecastable with any real confidence. It appears that this is one aspect of forecasting that warrants further research, seeking first to establish the nature of the problems in more detail, and then examining ways of detecting and forecasting small scale events. It seems likely that improvements in forecasting mesoscale phenomena would demand innovative approaches to presentation techniques.

In terms of verification procedures we have found that there are no standards which apply equally to all agencies providing services. Thus it is very difficult to make any assessment of relative performance. In a preliminary study of NORDCO Ltd. and

AES forecasts for the Grand Banks, we have found that neither organization consistently outperforms the other, although NORDCO, like other private forecasters, attempts to provide more detail in their presentation. There does not appear to be any basis on which to claim that provision of forecast services by private firms to the offshore is inadequate, relative to standards that could be established for the AES itself.

However, to judge the adequacy of forecast information to offshore operators, in an absolute sense, requires an assessment of how well the data meet their needs for making decisions that affect the security of their rigs and the safety of personnel at sea. To do this an examination of the entire relationship between regulatory expectations for offshore safety, the utilization of weather forecast data by operators to satisfy these expectations, in their central coordinating offices and on the rigs, and the ability of forecast agencies to provide the required data is necessary. In view of our conclusions on the information content and relevance of forecast data, on the one hand, and the apparent success of civilian aviation weather forecasting, on the other, we recommend the above type of study be undertaken.

Donald O. Hodgins, Ph.D., P.Eng.
Kenneth F. Harry, M.A.

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WEATHER FORECASTING SERVICES FOR THE CANADIAN OFFSHORE

Weather Forecasting Services for the Canadian Offshore

Part 1

Organization of Responsible Agencies

Prepared for

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1. INTRODUCTION

1.1 Statement of Study Objectives

The purpose of this report is to describe the weather and sea state services that are available to operators working in the eastern Canadian offshore from United States waters northward to approximately 70°N. This will be done by describing the existing services that are available to meet the needs of industry offshore. In the second report, to follow, an evaluation of the adequacy of these services is discussed.

1.2 Study Procedures

To meet the objectives two tasks were undertaken. First, a visit was paid to government (Atmospheric Environment Service [AES], Canadian Forces Weather Service [CFWS]) and private (MacLaren Plansearch, NORDCO, Mobil, MEP) offices in Halifax and Bedford, Nova Scotia, St. John's and Gander, Newfoundland and Toronto, Ontario. In early stages a visit was also made to Pacific Weather Centre in Vancouver, British Columbia particularly to see the satellite read-out system currently being put into operation there. The activities and capabilities of foreign based companies with involvements in the Canadian offshore have been assessed through a perusal of company literature.

Second, a literature review was undertaken to ensure that recent developments in data acquisition, forecasting and communications were identified so that if they are not under consideration or in use now, their ramifications on up-grading forecast services could be discussed in the second report.

1.3 The Nature of the Problem

Over the Canadian offshore, operators require weather and sea state data and forecasts to permit them to optimize their operations. With the introduction into weather forecasting in recent years of electronic data processing significant improvements have been made in the accuracy of longer range forecasts (Haering, 1981). In the short term, however, such improvements have been slow to appear -- to the extent that "Day-1 Forecasting" was chosen as the theme for the recent Canadian Meteorological and Oceanographic Society Congress (Smith, 1983). Therein it was stated:

> "The AES must improve its Day-1 weather warnings and forecast services. Emphasis will be placed on their dissemination, credibility, accuracy, verification and utility."

These commitments by AES to improve short (and inherently) longer term services are of particular importance in offshore areas where considerations of weather and sea state are matters of constant and often compelling concern.

2. THE ATMOSPHERIC ENVIRONMENT SERVICE

2.1 National Organization

In order that it can respond to the demands for service coming before it, AES at the national level has been organized into five directorates and one branch as shown in Figure 1. These are located at AES Headquarters, Downsview, Ontario with the exception of the Policy, Planning and Assessment Directorate which is co-located with the Department of the Environment in Hull, Quebec.

Of the directorates at Downsview, Field Services has been assigned the responsibility of providing a suitable level of weather services for the safety and security of Canadians and for the acquisition of the basic understanding of atmospheric properties needed to maintain and improve such services. As a response, weather forecasts and warnings are issued for all the land areas of Canada and for the contiguous ocean areas, generally within the 200 mile economic zone.

Six regional headquarters, shown in Figure 1, report through Field Services providing AES with essential regional contacts. Also reporting to this directorate is the Canadian Meteorological Centre in Montreal, the senior forecast office in Canada.

The Directorate of Meteorology and Oceanography (D MetOc), Canadian Forces Weather Service (CFWS) is staffed professionally by meteorologists seconded from AES, and the Director, based in Ottawa, reports functionally to AES (see Figure 1). This body has the responsibility for providing a meteorological and oceanographic service for Canadian Forces aviation, naval and land operations.

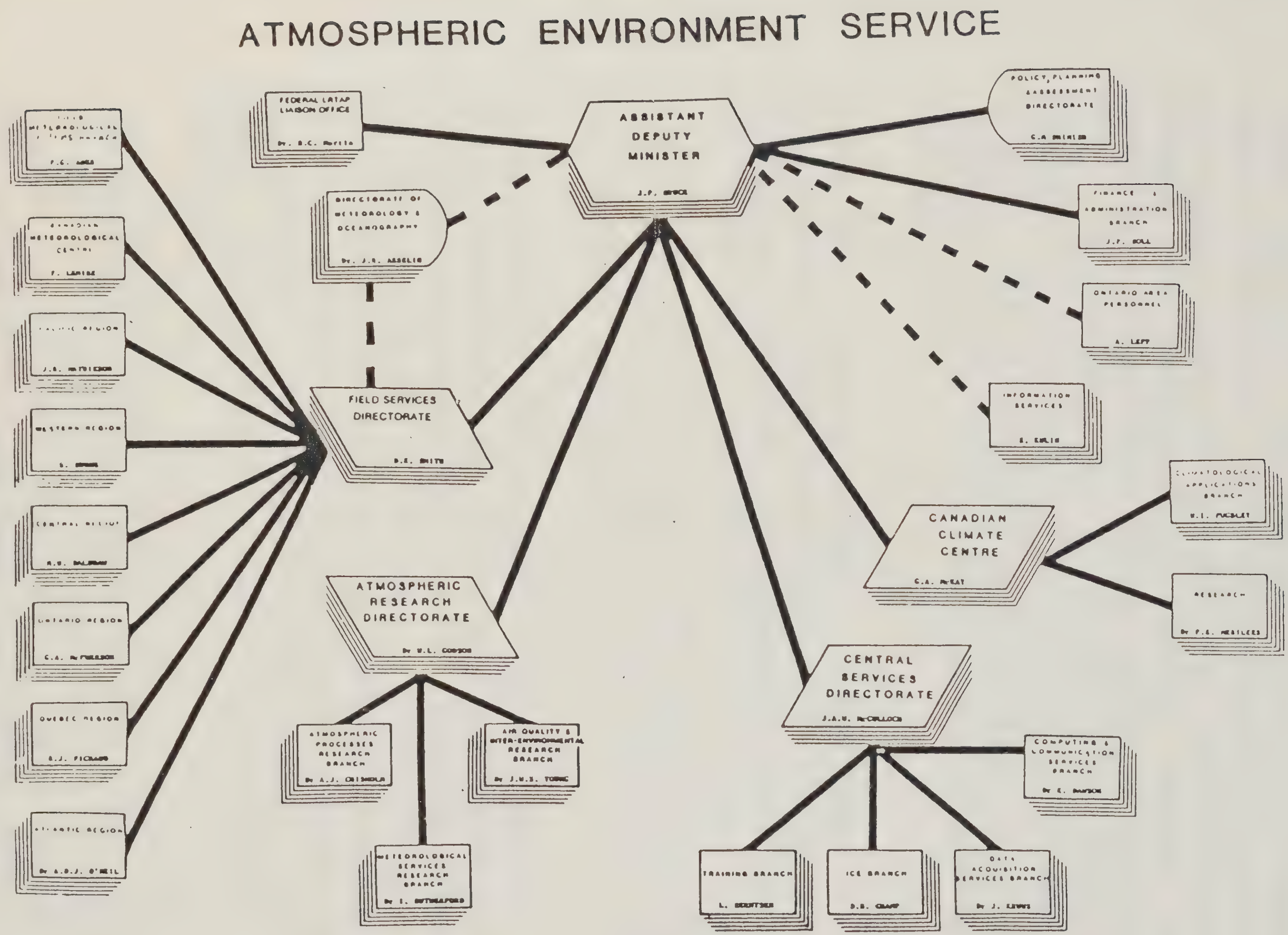


Figure 1. AES national structure. From AES (1983a).

The other directorates in Downsview have responsibilities which are of immediate importance in the provision of weather services. For example, within the Atmospheric Research Directorate, the Cloud Physics group is concerned with weather radar and thereby severe weather detection. Further, the Meteorological Services Research Branch (MSRB) is concerned with weather satellites and includes within it the Satellite Data Laboratory (SDL) which supplies real-time satellite data to AES. MSRB also develops both statistical and dynamical models and procedures for the forecasting elements of weather, sea state and ice.

Within the Canadian Climate Centre there is the Climatological Branch which collects and quality controls all surface, upper air and supplemental data (including that from ships at sea and oil rigs), provides hydrometeorological services for marine applications (Swail and Saulesleja, undated) and undertakes special study projects based upon climate data.

The Central Services Directorate in its own right and as a service organization for the other directorates provides computing and communication services, including management and operations of the AES national teletype, facsimile and photo-facsimile networks, the CMC computer system and the Downsview Computing Centre. It is also responsible for meteorological instrumentation within AES including design, testing and procurement of new systems and techniques.

Ice Branch, located in Ottawa, is responsible for the Canadian information and advisory service for sea ice distribution and type. Ice archives are maintained, and daily and seasonal ice forecasts are issued. Finally, the Central Services Training Branch in Downsview is

responsible for the recruitment and training of meteorologists and technicians and for the continuing professional development of those staff in AES.

2.2 Regional Organization

The six AES regions shown in Figure 2 have area responsibilities in the provision of weather services and in the collection and dissemination of weather information. The Atlantic Region, which includes the four Atlantic provinces and the offshore waters within the 200 mile economic zone, maintains a headquarters at Bedford, Nova Scotia. Within this regional organization there are four divisions reporting to the regional director. These are Weather Services, Scientific Services, Data Acquisition, and the Atlantic Weather Centre.

The Chief of Weather Services is concerned with the needs for and the provision of weather services in the Atlantic Region. He is also the regional officer responsible for the Newfoundland Weather Office (NWO) in Gander, Newfoundland and for the eight presentation offices in the Region, the locations of which are shown in Figure 3. In addition, he responds to stated meteorological requirements arising from the authorities of the Canadian Air Transportation Administration (CATA) and the Canadian Oil and Gas Land Administration (COGLA) relative to their respective responsibilities in aviation and offshore development.

The Scientific Services Division is responsible for data bank management, for the support of air quality services and for the review of environmental impact assessments. Scientific studies of regional concern in forestry, agriculture and the offshore are undertaken. In addition to staff at Bedford, scientific officers of the division

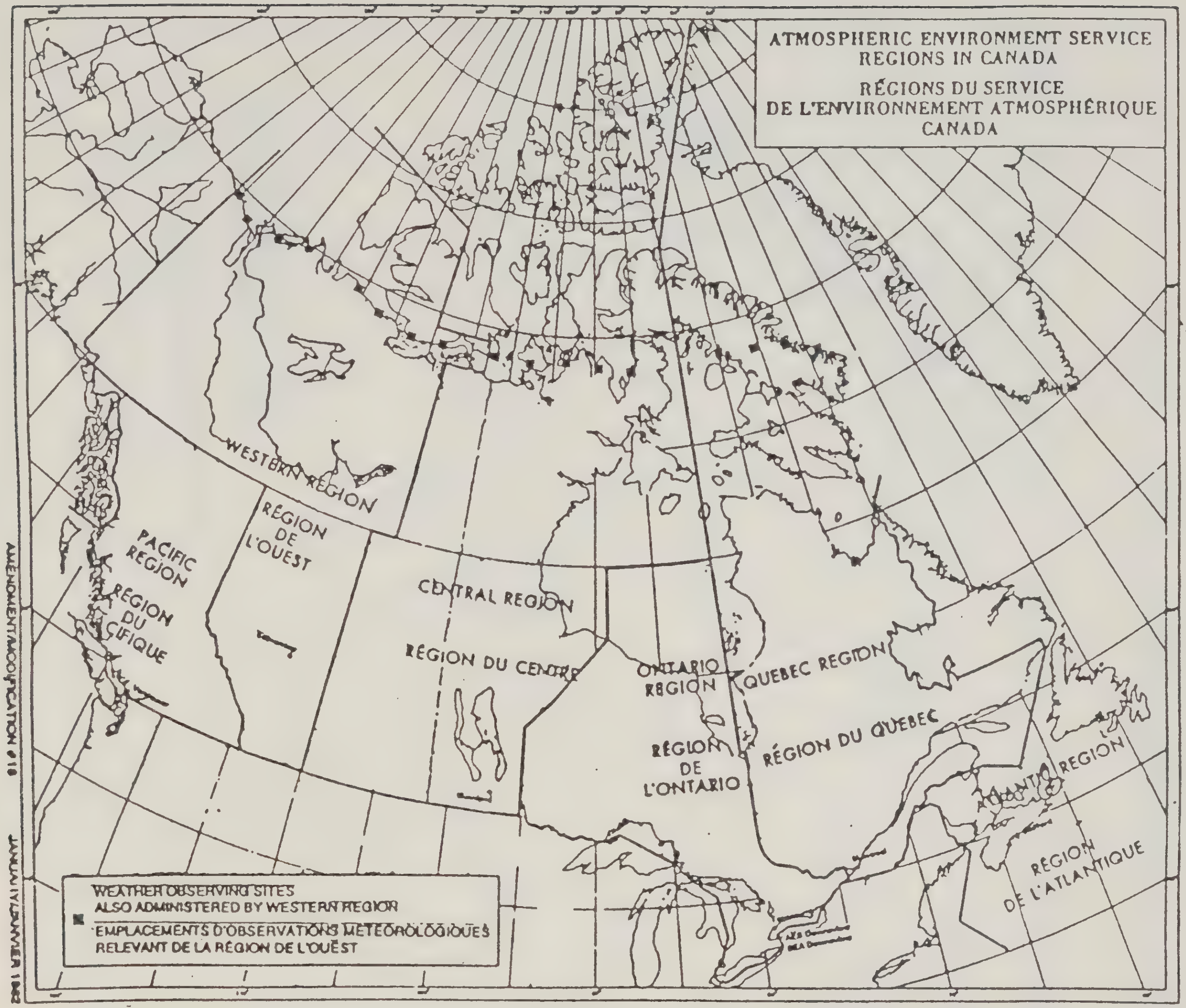


Figure 2. AES regions and their headquarters. From AES (1983a).

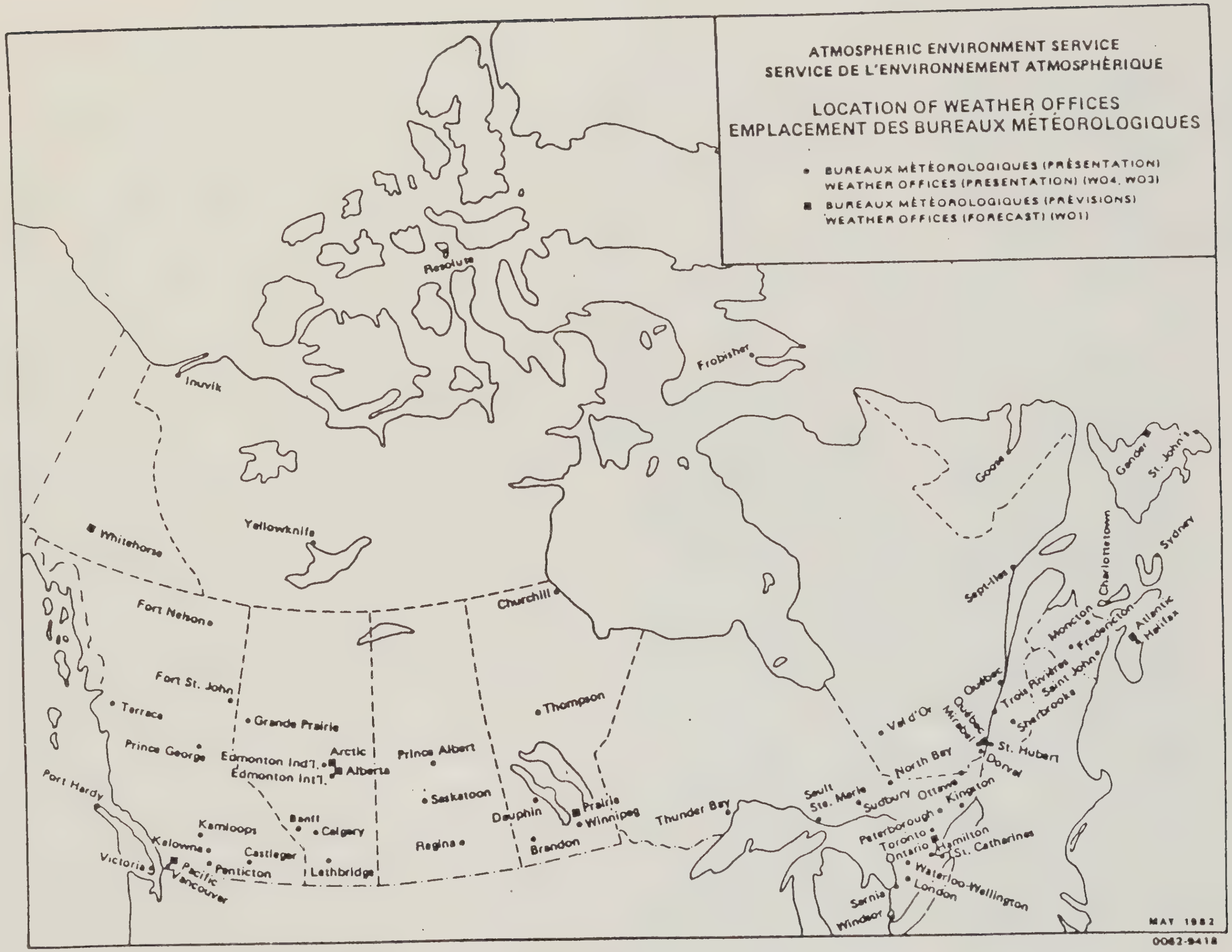


Figure 3. Locations of AES weather offices.
From AES (1983a).

are located at Fredericton, New Brunswick and St. John's, Newfoundland.

The Chief of Data Acquisition is responsible for regional data programs. This may involve station site selection, installation of equipment, and the subsequent inspection of equipment and staff performance. The training of staff, particularly of those working for private contractors or consultants, is also a responsibility.

The other major unit in the AES Atlantic Region establishment is the Atlantic Weather Centre which is located at Bedford as well. This office has the responsibility of providing analysis, prognostic and forecast guidance to other units (AES, CFWS and private) in Atlantic Canada and of leading in the operational development and training of regional meteorologists.

3. THE REGIONAL ROLE IN THE ACQUISITION OF METEOROLOGICAL AND SEA STATE DATA IN THE SUPPORT OF OFFSHORE DEVELOPMENT

3.1 Selection of Observing Sites

To meet requirements for meteorological data AES maintains in the Atlantic Region more than 30 synoptic and hourly reporting stations, the locations of which are shown in Figure 4. These are all land stations though some are located on headlands or islands and therefore, in some instances, have reasonable exposure to the sea.

To obtain data for the offshore, use is made of both ships of opportunity and drilling rigs. In the volunteer ship program suitable vessels are selected by the Port Meteorological Officers (there is one at St. John's, another at Halifax) and if the necessary cooperation is forthcoming, meteorological equipment is installed and training given to the ship's officers. The Manual of Marine Weather Observing (MANMAR) (AES, 1982) prepared by AES governs the procedures. Because of ship mobility and time restrictions, particularly of the radio officer, a program of even four synoptic reports per day is difficult to achieve.

Observational programs from rigs offshore are, however, a formal requirement as stated in "Physical Environmental Guidelines for Drilling Programs in the Canadian Offshore" (COGLA, 1983). Here observational requirements are stated, and they depend on factors such as the location of the rig with respect to an AES Weather Station (e.g. Sable Island) or whether the rig is used for helicopter operations.

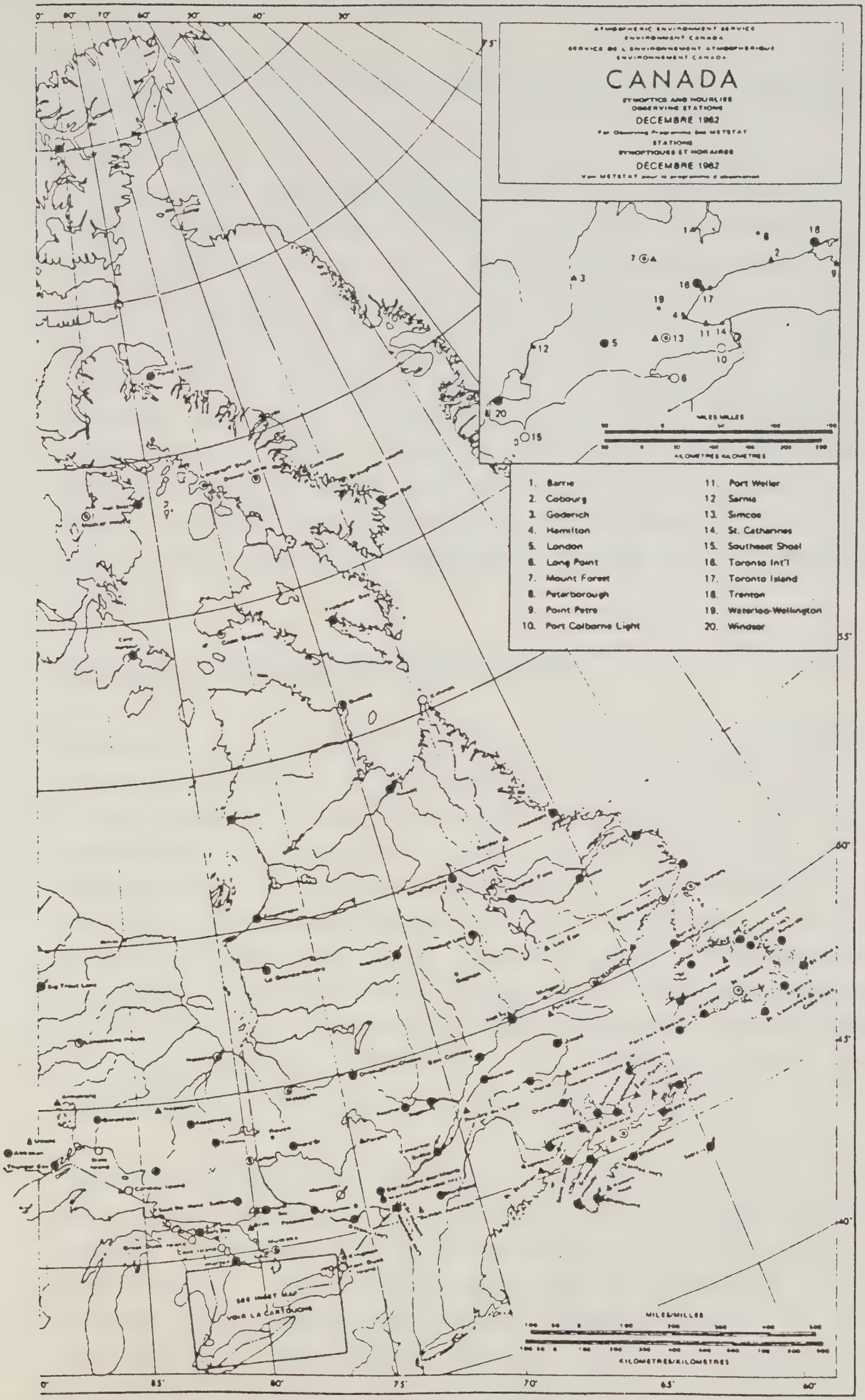


Figure 4. Synoptic and hourly reporting stations. From AES (1983a).

3.2 Training and Certification of Contract Weather Observers

If there is no aviation observing requirement the provisions of MANMAR (AES, 1982) are followed. The weather observers, most often employees of consultants, are trained for one week by the Regional Instructor, though if several are to receive instruction simultaneously, this may be done away from Bedford on a cost recovery basis. For an aviation program additional training by the Regional Instructor is required as observing programs are more complex. This training is based on the AES manual "Supplementary Aviation Weather Observation" (SAWRS) (AES, 1977). On successful completion candidates are presented with a certificate of competence signed by the Regional Director.

3.3 Supply and Installation of Equipment

Equipment in the MANMAR program consists of a Stevenson Screen in which are exposed dry and wet bulb thermometers, a sea bucket for determining water temperature, an aneroid barometer, a barograph and a non-recording U-2A anemometer. If aviation-style reports are required, then ceiling balloon equipment is also supplied. In many instances operators will install other meteorological equipment. Readings from these may be incorporated into the observations providing the equipment meets COGLA standards (COGLA, 1983) and is judged by the port meteorological officer to be properly exposed.

Usually, AES-supplied equipment is installed on the rigs when they are being outfitted either in Marystown or Halifax harbours. The anemometers, the most critical installation, are mounted as high as feasible on the derrick to produce the most representative of wind observations. The height of the anemometer above water

level is recorded and is available for the information of users of the data. The problems associated with the placement of anemometers on ocean structures so as to obtain useful wind data have been discussed in numerous reports, for example Dobson (1981), Pierson (1983), and Smith (1981).

3.4 Quality Control of Observing Programs

Quality control of rig observations is exercised in the first instance by immediate users -- the pilots and forecasters. Also, during the twice-yearly visits of the port meteorological officers, station procedures and records are reviewed. Beyond this, synoptic style (MANMAR) reports are quality controlled when they are introduced into the AES data bank at Downsview, and the aviation reports are routinely checked at Bedford where they are archived.

4. THE CANADIAN WEATHER AND SEA STATE FORECAST SYSTEM

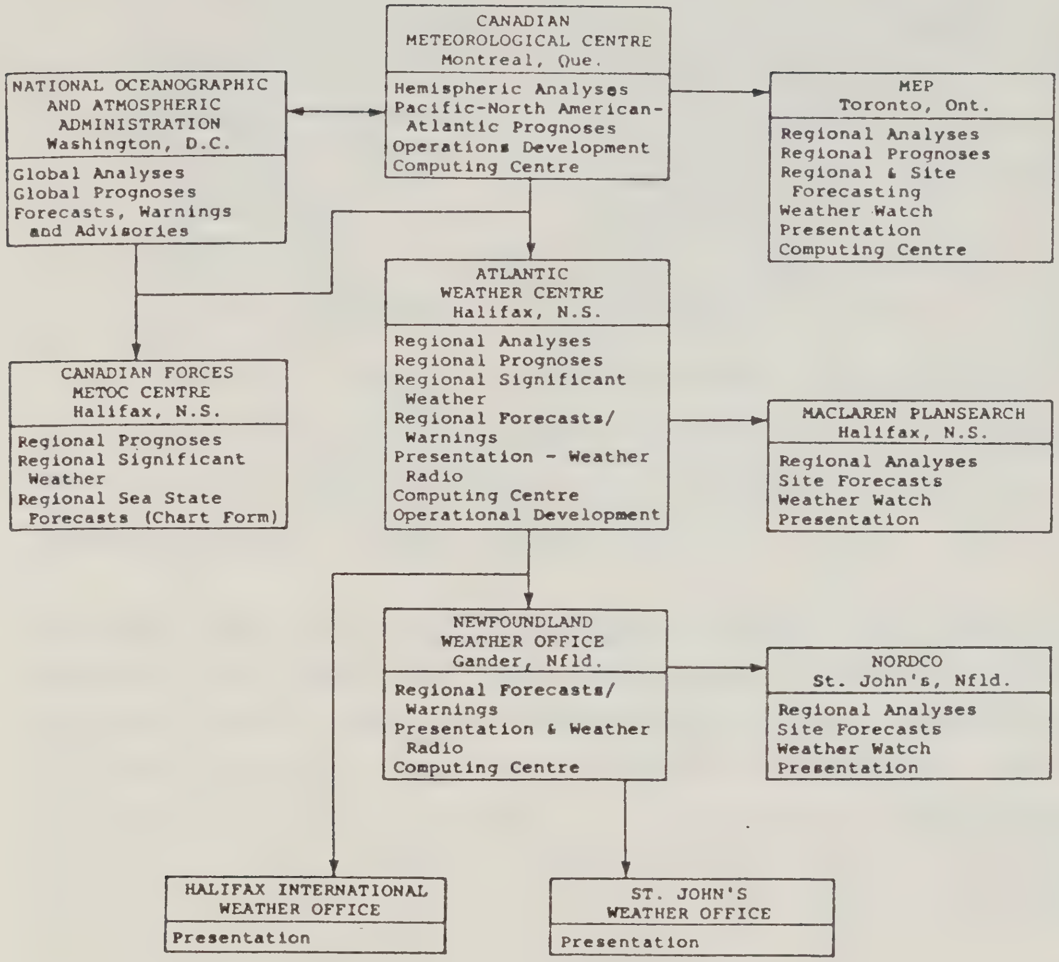
4.1 Structure

The system adopted by AES for the provision of meteorological, ice and sea state services in Canada is an hierarchical one based on diminishing geographical areas of responsibility. This structure is shown in Figure 5 which also illustrates the flow of information between the units. At the head is the Canadian Meteorological Centre (CMC) in Montreal. This office, by using computer-oriented techniques generates hemispheric analyses at the surface and in the upper air, and it provides synoptic scale prognostic guidance for North America and the contiguous oceans.

The next level of responsibility is vested in the Weather Centres of which there are seven in Canada (see Figure 3). These offices supply an analysis, prognostic and forecast service for their areas of responsibility using output from CMC as guidance. A mix of human and computer-oriented skills are used and outputs are in both chart and text form.

At a step below the Weather Centres are the forecast weather offices of which there are now just two civilian offices in Canada, Whitehorse and Gander (both identified in Figure 3). These offices are staffed to provide 24 hour forecast products.

Finally in the hierarchy are the presentation offices, sometimes headed by a meteorologist but most often staffed solely by specially trained meteorological technicians. Table 1 lists the eight such offices in the Atlantic Region and the nine in the Quebec Region (including Frobisher). Their activities are directed to meeting weather and sea state user needs.



Terms

Analyses and prognoses: chart form transmitted by facsimile.
Significant Weather: chart form transmitted by facsimile.
Forecasts/Warnings/Advisories: text form transmitted by teletype.
Presentation: verbal by telephone, Weather Radio (VHF), or video.

Notes

All offices except Presentation Offices receive SDL output directly.

St. John's WO, NORDCO, and Gander receive Trepassey radar imagery directly.

Figure 5. Heirarchy of public meteorological offices in Eastern Canada and the data flow from them to private companies.

Table 1

AES Presentation Offices in Eastern Canada

Quebec Region	Atlantic Region
Frobisher	Charlottetown
Montreal/Mirabel	Fredericton
Montreal/Dorval	Goose Bay
Quebec	Halifax International
Sept Iles	Moncton
Sherbrooke	Saint John
St. Hubert	St. John's
Trois Rivieres	Sydney
Val D'Or	

The Canadian Forces also has several weather offices in the Atlantic Region which are listed in Table 2. The senior office is METOC in Halifax.

Private weather firms (or consultants) may contract to acquire from AES the meteorological material needed to support their programs. While they function independently of AES direction they are required to consult with the appropriate office if there is a substantial difference in opinion (COGLA, 1983). Those private firms presently in operation are identified in Figure 5; their relationships to AES are discussed in Chapter 5.

Table 2

Canadian Forces Weather Offices

Atlantic Region
Chatham
Gagetown
Greenwood
Halifax (METOC)
Shearwater
Summerside

4.2 The Canadian Meteorological Centre Program

The output from CMC is largely in chart form, mostly produced by EDP methods using a CDC Cyber 176 computer and peripheral units. (The Cyber 176 is the most powerful computer in the Federal Government [AES, 1983a]). Based on hemispheric data received through the AES CNCP data network in Toronto, analyses and prognostics on a hemispheric or near hemispheric basis are produced. The prognostics include both surface and upper level charts issued for forecast intervals varying from twelve hours up to five days. A hemispheric spectral model in its eighth version is currently in use. These charts, which are hand-worked only to add frontal structures, are supplemented by forecast messages (FX) which are distributed by teletype to amplify the chart form forecasts. In addition to the surface and upper air charts a number of special fields (temperature, moisture, high level significant weather) are produced and distributed for use in the forecast offices. Operational development is an important part of the program at CMC that is directed toward maintaining a level of production in the Centre comparable with expertise elsewhere. Studies are regularly undertaken and the results distributed for consideration elsewhere (Boucaud, 1982).

Verification at CMC through the years has been done by means of the S-1 or Brier Scores (Teweles and Wobus, 1954). The scores are based upon pressure or contour height data extracted from prognostic and analyzed charts for the same time to provide a mathematical measure of forecast skill. In recent years with the implementation of EDP processes S-1 scores at CMC have displayed substantial improvements (Haering, 1981).

At the present time there is no systematic program for the

verification of severe weather situations at CMC although some work has been done (Boucaud, 1982; Gladstone, 1981). Because of the large grid used in determining the S-1 scores that system is not useful for verifying prognostic situations dealing with the intense, but compact cyclonic centres which are often the cause of strong winds over offshore waters.

CMC maintains the primary operational contact with the United States National Oceanic and Atmospheric Administration (NOAA is included in the hierarchy of Figure 5). Some of the analyses and prognoses of the National Meteorological Centre (NMC), Suitland, Maryland are fed directly into the Canadian weather-fax system through CMC. Of particular interest are the charts produced by the global spectral model (as compared with the Canadian hemispheric spectral model) and the Limited Fine Mesh (LFM) model. There is also a reasonable level of personal contact between these offices. For example during the hurricane season, when storms are positioned to be of concern to forecasters of both NMC and CMC, close coordination is maintained.

In Canada, personal contacts between CMC and Weather Centre meteorologists tend to be rather few and to be diminishing. With the more sophisticated numerical models now in use operational experience has shown it to be very difficult to successfully alter the data or patterns subjectively without causing inconsistencies or discontinuities. CMC meteorologists are therefore reluctant to make changes, and there is little reason to initiate contacts. However, during periods of severe weather, consultations are frequent.

4.3 The Atlantic Weather Centre Program

The meteorological program in Atlantic Weather Centre (AWC), Bedford consists of both analyses and prognoses in chart form and forecasts, weather warnings and advisory messages directed toward aviation, public and marine interests. In the mid-sixties during a reorganization which essentially produced the present day forecasting structure in Canada, the Atlantic Weather Centre was retained in downtown Halifax and the Maritimes Weather Office (WO1) at Halifax International Airport. In 1975 these two offices were co-located and subsequently merged into one within the Atmospheric Environment Centre at Bedford. The analysis-prognosis program output of the reorganized Weather Centre was retained in support of other AES and CFWS operations in the Atlantic Region.

The office is well-staffed (56 person-years including a professional staff of 24 meteorologists and three computer scientists) and is well-equipped. A Hewlett Packard mini-computer is an integral part of the office program and all weather charts and tephigrams are machine-plotted. All data are conveyed to the forecasters through video display terminals and all forecasts are composed on word processing equipment. Hard copy of teletype traffic is accumulated for record purposes but is not used in day-to-day operations. Data and forecasts are stored on magnetic tapes. Presently five years of records are available on tape at Bedford.

Satellite imagery is received from the Satellite Data Lab (SDL), Toronto by the new facsimile Unifax system. Both visual and infrared pictures are received but they are not colour-enhanced. To view a sequence of the satellite photos a video camera is used to produce a television film. Because of reduced definition though the system is not particularly effective (Horita, 1981).

Radar imagery is also available to the forecast office by relay from Halifax International Airport. Because of the location of the equipment, the information obtained has relatively little impact on offshore services.

The forecast programs from AWC are issued for the areas shown in Figures 6a (public), 6b (aviation), and 6c (marine). All forecasts are issued four times daily and amendments, weather warnings and advisories are issued when required. There are always three forecasters on duty and usually four on dayshift.

There is also a presentation technician on each shift to assist in forecast operations and to maintain the Weather Radio broadcast. The weather radio network in Eastern Canada has been particularly well exploited, with provincial cooperation, in the Atlantic Region. From the many, conveniently located VHF broadcast stations users always have available an immediate weather service. The stations in Atlantic Canada are shown in Figure 7.

The office has one meteorologist allocated to Operational Development, Implementation and Training. This person, in addition to being responsible for professional update training in the office has been much involved in the development of computer-oriented procedures for the office. This position is also the focus for operational research in the office from which Atlantic Region Technical Notes evolve (see, for example, Pearce, 1983a). While this kind of work is encouraged, relatively little time is available for it because of staff limitations.

The verification programs in use at AWC are those managed by Field Services (AES, 1982b) and since they have been in place barely a year they are not yet of much value to the forecast program. An internal program of verifying by

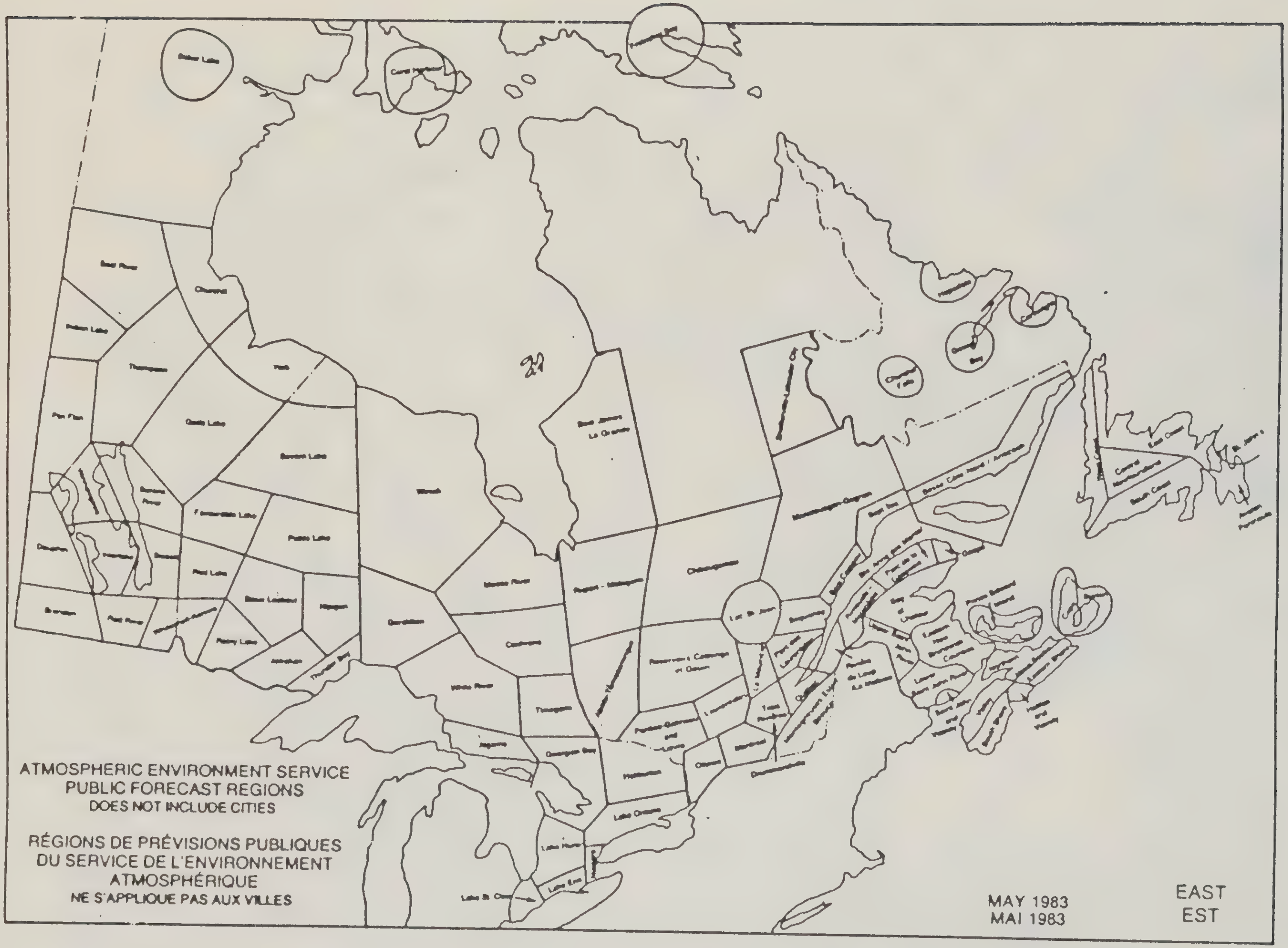


Figure 6a. AES Public forecast regions in eastern Canada. From AES (1983a).

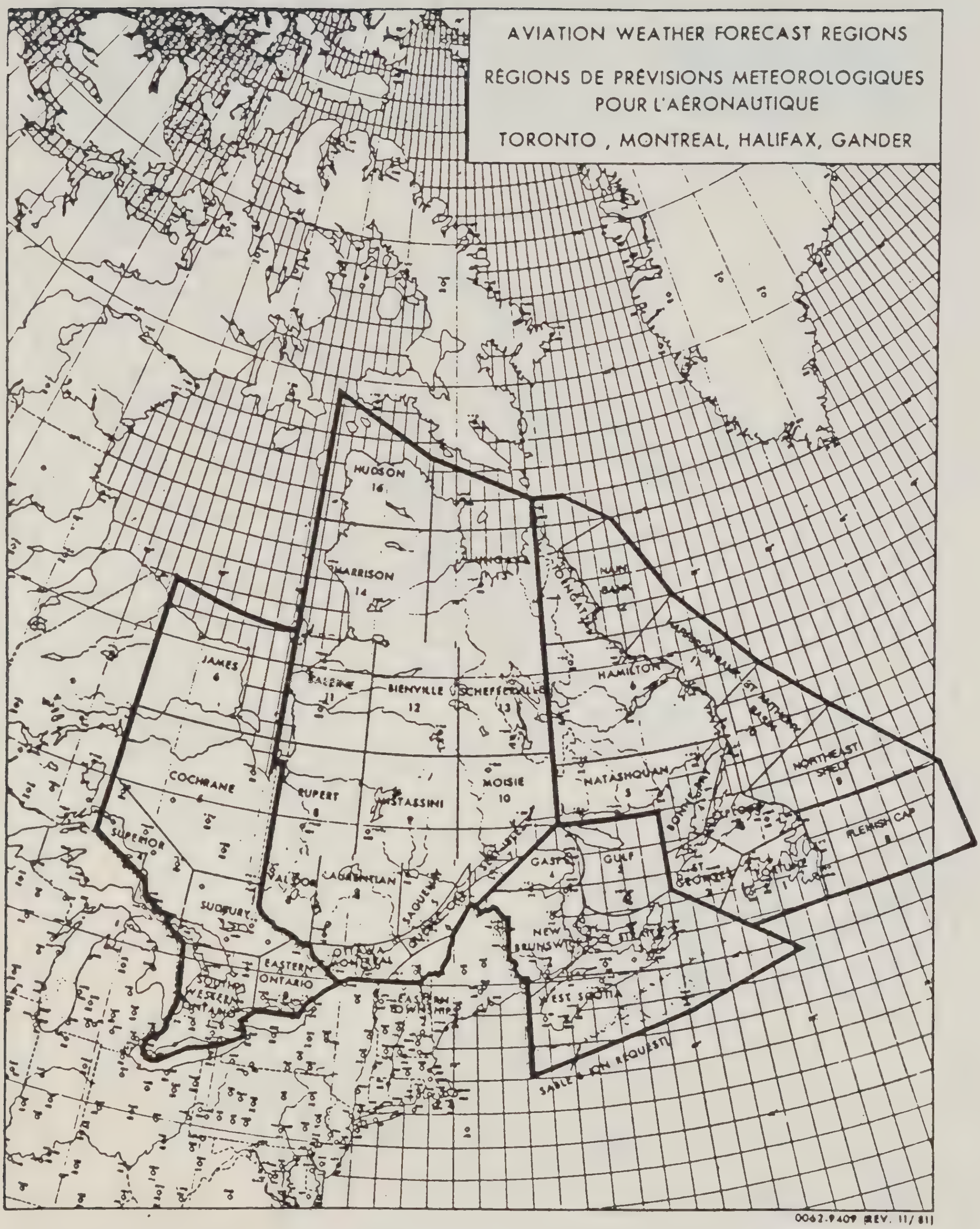


Figure 6b. AES Aviation weather forecast regions in eastern Canada. From AES (1983a).

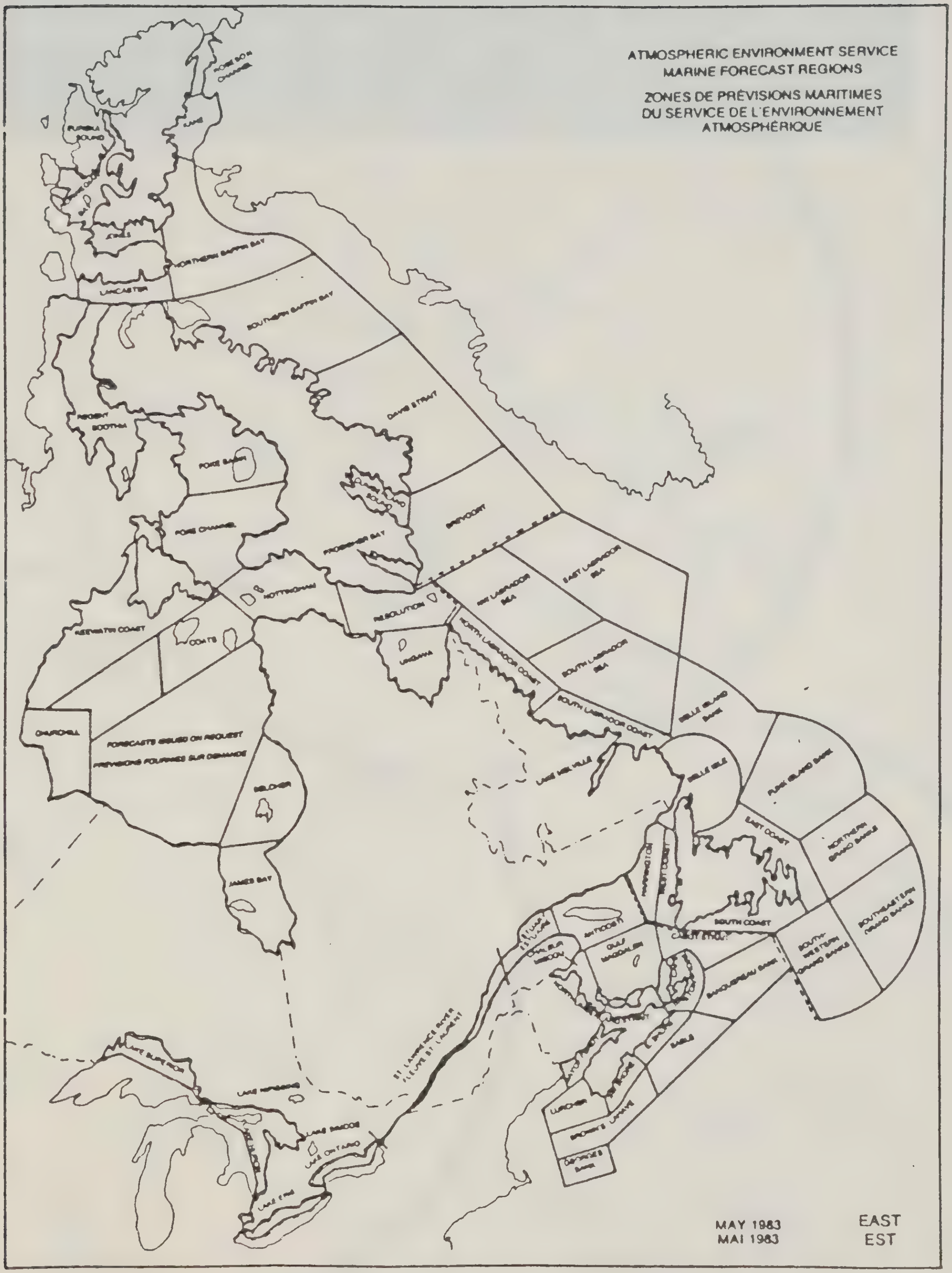


Figure 6c. AES Marine forecast regions in eastern Canada. From AES (1983a).

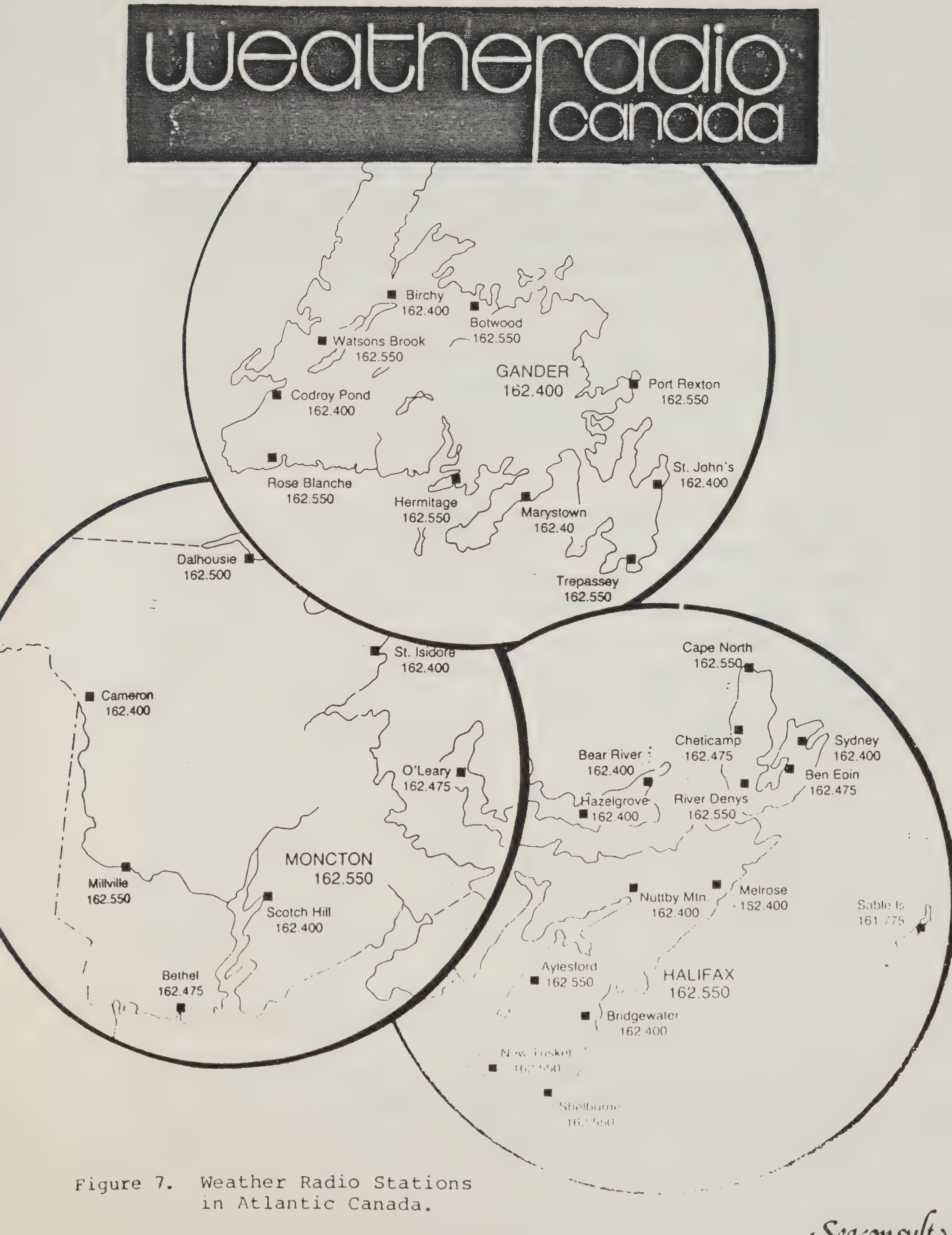


Figure 7. Weather Radio Stations
in Atlantic Canada.

means of the S-1 score based on the 30 hour surface prognostic has been maintained for almost 13 years and these scores which are posted in a time series in the office show indications of long term improvement. S-1 scores prepared more recently of the regional hand-done prognostic, the Global (NMC) and Hemispheric (CMC) Spectral Prognostics and the LFM (NMC) prognostic do not indicate that any one of these products is consistently better than the others.

As at CMC there is no program in place to verify office performance in severe weather events. However, a proposal for Marine Storm Warning Verification (Pearce, 1983b) is presently being discussed.

Inter-relationships between AWC and the staff of other forecast offices are infrequent. If hurricanes are a matter of concern then contact with NOAA hurricane forecasters in Miami is mandatory (AES, 1983c) and coordination with CMC meteorologists is encouraged. When other forms of severe weather are of concern then usually there is consultation with neighbouring U.S. offices (e.g. Boston, Massachusetts or Portland, Maine). However in more routine situations, even when differences of opinion arise, there is not much consultation because, apparently, it proves difficult to resolve differences satisfactorily by telephone. Only between the forecaster and the technician of the presentation office, who is frequently seeking information or explanations, are there regular interchanges.

4.4 The Newfoundland Weather Office Program

The Newfoundland Weather Office (NWO) program differs from that of the AWC in that it has neither a formal prognostic program nor an upper air analysis program. For these the

office is dependent upon the output of the AWC in Bedford and CMC in Montreal.

The forecast program consists of a full series of land area public and aviation forecasts and ocean area marine forecasts (Figures 6a, 6b, 6c) together with weather warnings and advisories as required. Also aviation forecasts for three ocean areas (Flemish Cap, Harrison Bank and Nain Bank) and seven sites are issued twice daily, with required amendments for the offshore industry. This tends to be a seasonal operation because of sea ice over more northernly parts of the offshore. Overall the program has grown considerably since its inception in 1978.

Another seasonal commitment arising from the offshore program in the Labrador Sea is a forecast provided to COGLA from early September until drilling activity is ended for the winter season. The emphasis in the two day forecast and three day outlook is placed on major storm activity. The information is used by COGLA to extend or terminate offshore activities as the exploration season draws to an end.

The professional staff of NWO consists of 14 shift meteorologists, a senior meteorologist and the officer in charge. There are two computer scientists in the office. Because of heavy summer commitments restrictions, of necessity, are placed upon summer leave. An important staffing consideration here is the short service periods of most professionals. Many stay for no more than the minimum two year posting and since the training period for recently graduated meteorologists is quite often lengthy, the professional staff resources are reduced accordingly. There is no operational-development position at NWO so there are no formal staff development or refresher training programs.

The equipment and facilities at NWO compare favourably with that of AWC in Bedford. There is in place a mini-computer which is used for data processing, printing of charts and composing and relay of forecasts. Satellite imagery is received via the Unifax facsimile circuit. Equipment to provide display of successive photos has been supplied but so far has not performed well.

The office receives in real-time, again by facsimile, the imagery from the Sceptre radar which is located at Trepassey on the south shore of the Avalon Peninsula. From the charts the forecasters can assess precipitation areas and intensities and can determine the vertical extent of precipitation producing clouds. Since the images are received at regular intervals speeds of precipitation systems, and thereby speeds of synoptic systems, can be determined providing there is a clear relationship between the two. With a normal scan area of 240 km the information is used primarily for forecast support for St. John's and the Avalon Peninsula but the information does have application in the near offshore.

Output from the Gander Air Traffic Control radar is also relayed into NWO for the use of the forecaster. However, since during precipitation events, controllers attempt to minimize the impact of precipitation on the screens, the usefulness of the facility is reduced.

Some verification of the Gander forecast product is done regularly. For example the Torbay (St. John's) and Gander terminal aviation forecasts were verified for a number of years. Now this is done through the national programs for aviation and public forecast verification (AES, 1983b). Precipitation forecasts for St. John's are monitored on a simple true or false basis.

For the offshore some attempt has been made to assess skill in forecasting strong winds (AES, 1983e) but difficulties are presented by the lack of useful verification data and therefore no regular program is in place. The presentation program in the NWO is an important function and as elsewhere it is maintained by meteorological technicians. A good deal of its effort is directed toward the briefing of pilots ferrying small aircraft to purchasers in Europe. The Weather Radio Canada program for Newfoundland (Figure 7) is also at NWO.

Another important thrust of the presentation program is the briefing of Canadian Forces Air-Sea Rescue personnel at Gander by remote video equipment supplied by Canadian Forces. The following information was obtained in an interview with Major Gathercole, the Officer in Command of the Air-Sea Rescue Squadron at Gander.

The Air-Sea Rescue Unit at Gander is responsible for both onshore and offshore emergency mercy missions and medical evacuations. These missions, using Labrador helicopters, may be flown anywhere from the U.S. border to well north of Frobisher Bay, N.W.T.

Operations are conducted under Visual Flight Rules which, in the often difficult weather conditions of the east coast, places considerable burden on the aircrew. Other operating restrictions are that there must be no airframe icing and no severe turbulence. Furthermore, winds on start-up must not exceed 52 kt nor should gust variations of speed exceed 15 kt. A particular operational difficulty offshore is presented by icebergs obscured by sea-fog.

To supplement "official" observations during missions, commanders will obtain information from available sources

such as the RCMP or lighthouse staff. The move by AES to replace manned observing sites by automatic equipment creates problems for Air-Sea Rescue operations since cloud ceiling and visibility are difficult to measure by automatic equipment.

Since location of equipment can be critical during severe weather events (e.g. decaying hurricanes), severe weather forecasts are watched carefully both in Gander and in Halifax where Air-Sea Rescue Headquarters is co-located with METOC in Canadian Forces Headquarters. If it seems useful to do so, equipment will be staged to critical areas in anticipation of emergencies arising from the severe weather.

Inter-relationships between NWO and the staff of other operations are the same as they are elsewhere -- quite good with those the office is serving (e.g. the presentation offices, Air-Sea Rescue) but less so with other meteorologists such as those at AWC or in private operations.

4.5 Presentation Offices in the Atlantic Region

There are eight presentation offices in the Atlantic Region of which four (Goose Bay, St. John's, Sydney and Halifax International) are most likely to have involvements with the offshore. In the Quebec Region, the Frobisher Bay Presentation Office may also be involved.

The offices are staffed by meteorological technicians on a 24 hour basis. In addition to maintaining an observational program, briefing service is provided to those with interest in public, aviation or marine meteorology. At St. John's, for example, the office receives over regional facsimile and teletype circuits all

weather charts, forecasts and related data in hard copy necessary to provide these services. Also, at St. John's, the Trepassey radar imagery is fed directly into the office for local use. Some satellite imagery is also supplied through the regional facsimile circuit from AWC. Because of the poor quality of the transmission and due to the need for professional assistance in interpretation, it is supplemented by "synoptic feature estimates" transmitted by teletype.

Because a close working relationship usually is developed with the meteorological client through in-person or telephone contacts, the presentation technician is an important element of the AES service hierarchy. Because of this personal contact aspect it is very important that effective communication be maintained between the presentation technician and the meteorologist. Within AES there has been discussion that could lead to a larger role for the meteorological technician in Weather Services (Lee, 1982). At the Sydney, Nova Scotia office, for example, a marine forecast program for the Bras D'Or Lakes is maintained by the technicians. Data from specially installed anemometers about the lakes are received in that office and it is judged that a better service can be provided if these special reports are utilized locally.

4.6 The Canadian Forces Meteorology and Oceanography Program

The Meteorology and Oceanography Centre (METOC) in Halifax has responsibilities in weather and sea state forecasting for both military and civilian users. It is a well-staffed facility with eight senior and six junior meteorologists, and the senior staff have a very low turnover rate. The centre operates 24 hours a day with at least one senior meteorologist in a supervisory role at all times.

METOC produces one sea state analysis chart and three prognoses charts every 12 hours. At about 0400 hours (GMT) they issue the 0000 hours analysis chart and the 1200 hours prognosis chart. At 0600 hours they issue a 24 and a 36 hour prognosis. A similar schedule is maintained between 1200 and 2400 hours (GMT).

The methods used by METOC to analyze and forecast the deep water sea state conditions are described by Morgan (1971). The wind prognoses are based on the CMC spectral analysis products and NOAA global wind fields together with subjective manual modifications. Wave prognoses are developed principally from the preceding analysis chart taking into account the predicted wind field changes and the observed trends in the wave field over the past 24 hours. In areas where predicted wind fields are likely to generate new waves, or where wave decay is expected, parametric wave models are used to supplement the wave field trend analysis. These models are based on mean wind speed, fetch and duration estimates, solved using nomograms derived by Suthons (1945) and Bretschneider (1953). This is largely a manual process which relies for its success on experienced forecasters. MEP of Toronto is presently under contract to provide a numerical wave forecast model which will be integrated into the METOC system.

As sea state observations from naval and commercial vessels and from drilling rigs become available, they are incorporated into the analysis chart. Care is taken to avoid introducing erroneous wave height reports.

The charts are distributed over the landline fax circuit and by radio fax on "fleet broadcasts" to the Canadian Navy and to commercial ships. Private forecast offices may also use these products, but the METOC schedule of

issuing prognoses is not compatible with offshore requirements.

The wave analysis charts are archived in the Bedford Institute of Oceanography (BIO) and thereby now form a 13 year historical database of deep water wave conditions in the North Atlantic. These charts have been digitized by BIO as well as by AES and the resulting database is available from the Marine Environmental Data Service in Ottawa.

5. PRIVATE METEOROLOGICAL COMPANIES

There are presently three private Canadian companies which provide meteorological forecasting to the Atlantic offshore operators. In Figure 5 their relationship to the AES structure was shown. In addition there is one American firm currently providing services for drilling operations in Canadian waters. The following sections describe the facilities and services of these four consulting companies with emphasis on those located in Canada.

5.1 MacLaren Plansearch

This company conducted weather and sea state forecast operations in Newfoundland in the 1978/79 period and since October 1982 has been supplying services to operators on the Scotian Shelf from an office in downtown Halifax. The office, while small, is equipped with the available AES facsimile, teletype and satellite imagery (Unifax) circuits. No computer is available and as a consequence the surface weather charts and aerodynamic diagrams used in the office are hand plotted.

At present one meteorologist per shift (without technical support) maintains the office, issues the forecasts and carries out a weather watch. Management indicated that technical staff would likely soon be added. The core forecasters are three British-trained meteorologists who have had offshore experience in Britian and the near-east. This staff is supplemented by retired AES meteorologists.

Weather warnings, weather and sea state forecasts are issued for the mandatory 48 hour forecast and 72 hour outlook periods (COGLA, 1983). In support of this program

surface weather charts are plotted and analyzed for each of the four synoptic hours with data coverage regularly ranging from the eastern one-third of North America to the eastern Atlantic. There is no formal prognostic program. Telephone contacts with AWC forecasters are infrequent.

Forecasts are issued every 12 hours and are regularly up-dated six hours after issue. They are delivered by telex to company radio rooms for onward transmission to the rigs. The forecasts are regularly verified against rig data and monthly summaries of site weather are prepared. No formal attempt has been made to verify the handling of severe weather events to date. Weather watch is regularly maintained and considerable importance is placed on good working relationships between rig and weather office personnel.

5.2 Newfoundland Oceans Research and Development Corporation (NORDCO)

NORDCO is a diverse environmentally oriented company that has, as part of its business, been providing weather and sea state observing and forecasting services for the eastern offshore for several years. The forecast office is located in St. John's, Newfoundland and is equipped with normal AES circuitry. (The K560 glossy print system for receiving satellite imagery has been retained in preference to the duller prints of the new Unifax system.) Output of the Trepassey radar is also received regularly. To handle the forecast output telex equipment with an incorporated word processing system is used.

There are six meteorologists, including the manager, on staff so that normally a meteorologist is available to assist the manager in program development. There is also one technician on duty per shift. The professional staff

are Canadian-trained and are considered by the manager to have qualifications equivalent to AES forecasters executing normal shift forecast duties.

The analysis program consists of four hand-plotted and hand-analyzed surface charts that, as at MacLaren Plansearch, approximate the plotting areas of the AWC or NWO charts. There is no formal prognostic program. Forecasts, provided presently to as many as ten sites, are issued with respect to a formal manual of operations which is made available to each client. In the manual (e.g. see Exhibit 112, Ocean Ranger Royal Commission) the parameters that may be included in the forecast are listed and the terms on which they are forecast are rigorously defined. Forecasts are normally issued in tabular form for periods up to 48 hours and are regularly supplemented by less specific outlooks for periods beyond the forecast (COGLA, 1983). In the forecast process it is considered at NORDCO that the forecaster's judgement is used to narrow down the scale of weather prediction and that elements are defined at the mesoscale as well as the synoptic scale (CMOS, 1983a; 1983b). For example, winds are forecast for the anemometer height thereby anticipating turbulence factors that are inherent with the location of the instrument.

Verification programs are maintained as a requirement (COGLA, 1983) and the rigorous definition of the forecast parameters provides for relatively easy application of verification rules. As a matter of personal concern the manager has written on the subject (Hewson, 1983) and suggests than an assessment of "usefulness" of the forecast to the client may be more appropriate than an objective assessment of "accuracy." Concerning severe weather events there is for these no continuing program to objectively assess forecaster skills.

In the matter of having one company supply both observing and forecasting services to a rig the following comments in support of such an arrangement were obtained:

- qualifications of staff at both ends are understood,
- manual of operations is understood,
- systematic errors in forecasting may be more readily recognized,
- inter-company competition or friction is eliminated, and
- formal and informal contacts between rig supervisory staff and the forecaster are encouraged.

5.3 Meteorological and Environmental Planning Ltd. (MEP)

MEP is an environmental consulting company which has been involved in weather and sea state forecasting for the past ten years (MEP, 1983). While not presently providing services in the eastern Canadian offshore there recently were commitments in both observing and forecasting in the Labrador Sea.

The MEP operation is sophisticated featuring a substantial computer operation directly linked to the AES CNCP data bank and software developed in-house for internal manipulation of data. Map and tephigram plotters are available, and forecasters can call up plots for areas of interest on a 6, 3 or 1-hourly basis. Satellite imagery received via a K560 photo recorder from SDL is regularly used as an analysis aid.

AES (and NMC) prognostic charts are used as guidance for the in-house prognostic program which consists of 24, 36 and 48 hour prognostics. The short term (24 hour) prognostic is a combination of short range hand-applied techniques and computer output.

Shift staff is normally one forecaster and one technician. CRT procedures are employed in preparing all forecasts and considerable use is made of video graphics in monitoring weather and forecast relationships by means of time-series. The forecasters are required to have Canadian university training to M.Sc. level and most also have the benefit of AES training. Technicians usually have either AES or CFWS training. All forecasting is done in Toronto and is delivered to clients through MEP supplied circuits. On-site briefings for clients may be made available on a 5-day week basis with emergency call-out at other times.

Verifications of products are regularly maintained by correlation between forecast and observation and by comparison with persistence and climatology. Skill in forecasting low pressures in terms of central pressures and location of centres is routinely assessed.

5.4 Weather Service Corporation (WSC)

Weather Service Corporation in Bedford, Massachusetts is currently providing meteorological services on the Scotian Shelf. It is a large, long established (1946) firm of meteorological consultants (WSC, 1982) based in the United States which provides weather services in a number of fields. Staff consists of as many as 30 meteorologists providing a 24 hour forecast and weather watch program which is strongly supported by computer capability in the storage and manipulation of data, chart printing and forecast preparation.

Since the office was not visited no attempt to supply further detail is made. It is understood that in their present contract on the Scotian Shelf, the company does not supply a locally-based weather watch or briefing service.

6. SPECIAL AES/INDUSTRY COOPERATIVE PROGRAM

Since 1976 the Beaufort Weather and Ice Office has provided support to offshore exploration in the Beaufort Sea. This service, provided under contract to industry by the Atmospheric Environment Service, is described in the AES (1983d) report.

The program of this office in cooperation with Ice Forecasting Central in Ottawa provides to industry a meteorological, ice and sea state data service and a related forecast program. Seasonal reviews of significant storms and day-to-day weather, sea and ice summaries are provided along with formal verification of the forecast parameters.

Although no visit was made to this office perusal of its most recent annual report suggests its structure should be of interest to the eastern offshore program.

7. DEVELOPMENTS IN WEATHER-RELATED PROGRAMS

7.1 Data Acquisition

7.1.1 Existing Satellite Technology

Although imagery from the NOAA polar-orbiting and geostationary satellites is used in a routine fashion in the preparation of forecast products for the East Coast, its potential is not being fully utilized. For instance the Atlantic Weather Centre does not have the capability to receive and analyze the digital information coming from the satellites. The Pacific Weather Centre, however, has a reception and analysis system under operational development (Horita, 1981) which allows colour enhancement of the imagery and creation of films showing the evolving meteorological patterns from a series of images. These analytical techniques have become quite useful in preparing forecasts as they permit detailed study of cloud and sea surface temperatures and of the kinematic features of pressure systems. Although the capability of the Pacific Weather Centre is not quite state-of-the-art it is considerably more advanced than that presently available at AWC.

7.1.2 Anticipated Satellite Developments

Research in the area of remote sensing has resulted in the development of a number of satellite sensors that appear to have considerable potential to enhance offshore meteorological forecasting. Radar scatterometers, through their measurements of wind speeds over a 130 km swath, could be of great value not only in measuring offshore winds but in defining fronts and wind shift lines from those wind fields. Radar altimeters may be employed to define the spatial variations in wave height along the

satellite track and synthetic aperature radars (SAR) can be used to determine wave heights.

7.1.3 Buoys

The use of meteorological buoys which telemeter their data by satellite has been demonstrated quite successfully in Canada. Drifting buoys have been used along the East Coast (Labrador principally) and the West Coast for the collection of air and sea temperatures and of atmospheric pressure. Buoys with fixed moorings have been used in the Labrador Sea, Davis Strait and on the Scotian Shelf to measure the standard meteorological parameters (except ceiling, visibility and in some cases wave height and period). Although the deployments have often extended over several months, none on the East Coast were established on a permanent basis. In spite of the usefulness of the data for marine forecasts, Canada does not routinely use these systems on the East Coast. The reasons are threefold:

- the inoperability, particularly of fixed buoys, in sea ice;
- the expense and logistical difficulty of deployment and recovery; and
- the expense of acquisition and maintenance (large moored buoys cost about $1 million with annual maintenance costs of the same magnitude).

Although the drifting buoys are cheaper (about $15,000) they provide only a small subset of the data available from the moored version. Furthermore because they drift, they only remain within useful range for about two weeks. Hence the frequency of deployment, or recovery and redeployment, is high. It is expected that the meteorological buoys will be required to provide

calibrations of the new satellite sensors discussed in the previous section.

7.1.4 Land Based Doppler HF Radar

Although not used anywhere in the world at present in a routine fashion, a HF skyway radar system has been shown to be capable of measuring winds at a site 3000 km away by looking at the doppler shifts in the radio waves back scattered from the very short ocean waves (Stewart and Barnum, 1975). Although the technique is somewhat dependent on ionospheric conditions the potential exists to measure open ocean surface wind speeds from a land based station up to 3000 km away. There is no known active research in Canada on this system.

7.2 Communications and Data Processing

Regional experimentation using satellites for voice transmission gives an indication of easier and thereby more effective communication between rig and shore personnel. Such developments should put forecast office capabilities more effectively at the call of offshore staff.

Exploitation of computerized graphical display methods coordinated with satellite communications shows promise in improving the availability of forecast and observational data in the offshore. Indications are that on-demand access to these data in the offshore will shortly be available through Telidon related systems.

AES is conducting trials with a digital facsimile system to produce cleaner, more readable copy, and doing so at speeds up to seven times faster than the existing system.

Successes in numerical weather prediction at the European Centre for Meteorological Forecasting in Germany using the Cray (a Vector computer) has encouraged AES to adopt the new equipment. This facility will provide much faster execution of the arithmetic operations in meteorological modelling. The installation of a Cray at CMC in February 1984 is expected to improve S-1 Scores, extend forecasting skill into Day 6 and improve the uneven performance for warnings of severe storms 24 to 48 hours in advance (AES, 1983f).

8. SPECIAL REQUIREMENTS AND PROCEDURES FOR THE OFFSHORE

8.1 Weather Sensitive Operations

Most offshore activities are sensitive to one or more aspects of weather, and indeed "waiting on weather" may be the major cause of downtime in harsh environments. The primary activities, the meterological environmental factors and their interdependencies are catalogued in Table 3. The activities encompass those associated with drilling the well itself and those ancilliary tasks which involve diving, supply vessels, fixed-wing aircraft or helicopters.

The environmental factors in this table have been extended to include water temperature because it is a meteorological parameter and daylight, the only one in the set which can be predicted with accuracy. Although waves result from wind forcing and are more troublesome for most activities, there are situations in which wind is either an additional factor (such as in resupply from ships) or an independent force (e.g. helicopter transport). Hence wind and waves are accepted as two distinct parameters.

In constructing Table 3 the sensitivity of each activity to each environmental factor has been considered and ranked as strong, weak or no dependence. To keep the activities list to a manageable length, some entries encompass a wide range of tasks and the designated sensitivity may not apply equally to all such tasks.

With respect to the safety drills activity, it is understood that there is a general reluctance to call these drills in foul weather due to the increased risk of injury under such conditions. At present, life boats are not launched during rig abandonment practices at sea;

Table 3

Dependence of Offshore Activities on Weather

ENVIRONMENTAL FACTOR / ACTIVITY	Drilling	Casing	Cementing	Logging	Testing	Tripping	Down Hole Problems	BOP Handling	Diving	Resupply With Vessels	Transport Helicopters	Visual Iceberg Detection	Radar Iceberg Detection	Iceberg Towing	Rig Anchor Handling	Rig Towage	Rig Inspection at Sea	Safety Drills	Search/Rescue Area Planning	Search	Rescue
Wind										☆	★			☆	☆	☆		☆	★	☆	☆
Waves	☆	★	☆	☆	☆	☆	☆	★	★	★			☆	★	★	★				☆	★
Icing									★	★	★			★	★	☆	★	★		★	★
Fog									☆	☆	★	★		☆	☆	☆				★	☆
Precipitation									☆	☆	☆	★	★	☆		☆		☆		★	☆
Air Temperature										☆	☆				☆		☆	★			☆
Water Temperature									☆												☆
Daylight									★	☆	★	★		☆	★		☆	★		★	★

Key: ★ strong dependence
☆ some sensitivity

hence waves, fog and water temperature have no bearing on safety drills. Recent industrial reviews of these aspects of preparedness at sea may alter procedures for such exercises and thereby increase the sensitivity to weather.

It is apparent from Table 3 that offshore operations may be severely hampered by inclement weather. Thus accurate weather forecasting would allow optimization of both drilling and service activities. More importantly, these inter-relationships clearly suggest that inaccurate prognoses or untimely delivery of forecasts can complicate operations like diving or helicopter transport and in doing so increase the risk to the lives of offshore workers.

8.2 Systems Operations Control

For their operations on the Grand Banks, Mobil Oil Canada, Ltd. in St. John's has established an environmental operations group and assigned it the responsibility of providing an interface between shore-based staffs, the various weather and sea state offices, and the rig operating personnel. This group regularly receives a personal briefing from their consultant (presently NORDCO) and is prepared, if the situation appears to be difficult, to consult with forecasters in the Newfoundland Weather Office and/or the Atlantic Weather Centre, or with staff of Weather Services Corporation in Bedford, Massachusetts, or the Institute for Storm Research in Houston, Texas.

This system, by which company consideration of alternatives is placed in the hands of specialists, results in a 24-hour operational commitment and provides, in principle, offshore staff with a more uniform, more stable and more effective weather and sea state service.

8.3 Private-Sector Verification

As an active participant in the Canadian offshore, Mobil has taken initiatives in verification. For example, NORDCO has been reviewing routine forecasts for the past two years and while emphasis was initially directed toward the continuing aspects of the weather, attention more recently has been focussed on severe events. To date four 1981 and six to eight 1982 storms have been examined by NORDCO for Mobil in rather voluminous reports, copies of which were not available at the time of writing. In another program MEP Ltd. in Toronto has been verifying AES forecasts prepared by AWC for specific Mobil sites near Sable Island.

9. SUMMARY

This report contains the findings of Phase I of our assessment of the adequacy of observation and weather prediction services provided in support of eastern Canada offshore drilling operations. The emphasis has been placed on documenting the structure of the Atmospheric Environment Service and on identifying the flow of meteorological data through AES to its regional offices and to private forecasting companies. Through personal interviews, we have been able to provide preliminary commentary upon generally undocumented factors such as the inter-relationships between the various offices and the extent of verification of their data products.

This description provides the necessary background from which we can begin an assessment of forecast adequacy. Stage II of the present study will examine in more detail the types of data products disseminated by the responsible forecast agencies, and forecast performance for a number of case-study storms. The emphasis will be on severe weather which, as we have found, is only recently beginning to receive the attention it deserves. The acquisition and utilization of meteorological data will also be examined.

One of the most difficult aspects of this assessment is defining criteria by which one can judge adequacy. It has become apparent that little or none of this information is written down and accessible through the usual type of literature review. Rather, specific criteria may well have to come out of long experience at sea or in the air, and be formulated by interviewing senior personnel connected with these operations. We will examine this aspect of the problem further in Stage II of the present study with a view to recommending approaches to its solution.

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Weather Forecasting Services for the Canadian Offshore

Part 2

Assessment of Adequacy

Prepared for

The Royal Commission
on the
Ocean Ranger Marine Disaster

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1. INTRODUCTION

It is self-evident that many aspects of offshore exploratory drilling for oil and gas are affected, in varying degrees, by weather. From two points-of-view, safety of operations and efficiency of the drilling program, accurate weather forecasting would appear necessary. The present study has described the agencies that are responsible for providing forecasting services to the offshore (Part 1), and in this report, examines the question of adequacy of the forecast content and presentation.

Our emphasis is on severe weather because these situations are most relevant for human safety and for preventing expensive losses of equipment or operating time (see e.g. LeBlanc, 1981). It should be borne in mind that accurate forecasts of prolonged fair weather may also be very important in planning operations, but are of much less interest to safety considerations. This is also a useful distinction in terms of how forecast verifications are made. Scores or indices which tend to combine fair and foul weather performance into one number are not useful for documenting how well changes in weather, or the peak response in storms, are predicted. We will return to this point later in our discussion of performance and its relation to assessing adequacy.

The first report in Part 1 concentrated on how the forecasting agencies in Canada are organized and how they interact to derive forecast information. What we have found is a very hierarchial structure, from national, to regional, to dedicated site-specific forecasting groups, that provide ever more detailed presentations as their geographical areas of responsibility diminish in size. They all, however, share the same basic information,

although one might argue that the site-specific forecasters take better advantage of offshore data resources through a kind of small-area focus of attention. What we do not find is any significant introduction of new technology, with the possible exception of the MEP Company in Toronto, that represents a departure from procedures used by the Atmospheric Environment Service (AES). Thus we have several kinds of forecast presentation, originating with different agencies, but all flowing out of the same nationally organized modelling and data acquisition programs, and derived using the same principles.

As part of the assessment of these forecast services, recent developments in data acquisition and the use of satellite imagery are discussed in this report. These will be used here as a basis for discussing the resolution of weather systems, in relation to current thinking in mesoscale meteorology. A description of severe weather conditions relevant to the Canadian offshore is presented next, together with new results from verification studies on seven Grand Banks storms. These are followed by a description of forecast preparation and presentation identified with the responsible agencies. Meteorologist staffing, as a problem for maintaining and up-grading services is then examined, and our conclusions, with recommendations for further study, are presented in the final chapter.

During 1983 there were three important scientific events timely to this study. In order these were the Mesoscale Meteorology Research Planning Workshop in Toronto on January 24-26 sponsored by the Scientific Committee, Canadian Meteorological and Oceanographic Society (CMOS); the Fifth Symposium on Meteorological Observations and Instrumentation in Toronto on April 11-15 sponsored by the

American Meteorological Society; the Seventeenth Congress, CMOS in Banff on May 3-5. Proceedings and individual papers from these conferences were consulted quite extensively in preparing this report. Another source of pertinent information is an internal AES document "The Canadian Forecast System Review, A Summary Report" written by P.J. Pender (1983). This document, which is still under review within AES, was useful here inasmuch as it provided a perception of the Service from within.

2. DATA ACQUISITION

Successful weather forecasting depends strongly on having data that are accurate, well distributed spatially, and available in a timely manner to the forecast team. These data, blended with past forecasts, provide a description of present weather upon which the prognoses are based. It was logical, given the scope and expense of meteorological data collection and the fact that, until recently weather forecasting was done exclusively by governmental agencies in Canada, that AES should be the lead agency in data acquisition, quality control and transmittal as forecast services evolved. Over land an extensive observing network has been built up, that supports, at least in the view of AES, an acceptable level of forecast service through the data acquired. However, difficulties inherent in establishing and maintaining offshore stations undoubtedly lead to less accurate and more sparse data over the ocean.

Those data which are available in time to prepare analysis products are accessible over CNCP telecommunication networks; they are described in more detail in Part 1 of this report. Within the scope of this work it has not been possible to examine how effectively this observing and reporting really functions. It is an area which could be fruitfully examined in the context of this study, but is less important than the issues addressed here. It is an aspect of forecasting which we recommend for detailed study at a later stage.

However, justified by arguments of increased accuracy and frequency, and efficient transmission of data as well as reduced cost, there has been an evolution within the observing organizations to more automated equipment. These developments do have an impact on the quality of

information available to forecasters and hence affect the accuracy of predicted weather. Four areas of automated (i.e. non-human observing) data collection are briefly discussed here to point out some of the potential, some of the less obvious limitations, and to comment on how they affect forecasting over Eastern Canadian waters. The four applications concern automated weather stations, wave buoys, instrumented offshore structures, and satellite imagery.

2.1 Utilization of Automatic Weather Stations

2.1.1 Land Sites

In Canada the use of automatic weather stations has proceeded to the extent that by 1983 sixty-four have been installed (AES, 1983a). Of these, nine are in the Atlantic Region. Typically the measured parameters include wind speed and direction, pressure, temperature, and dew point. But because of sensor limitations or site restrictions some parameters normally obtained at manned stations are missed -- cloud amount, cloud height and visibility are examples. Also because of the need for assured power these stations are not always located where the data are the most representative or most valuable. Thus data from automated stations do not always provide the benefits which are available in principle from such instruments and may, in fact, represent a degradation of information from that available from manned locations.

Recent developments in sensor and microprocessor technology have brought completely automatic weather stations, capable of meeting even aviation requirements, to the available or near-available stage (Schmidt and Zbar, 1983; Van den Enden and Jansen, 1983; Jurvanen, 1983). In fact where commercial power and telephone

services are available it has been demonstrated that a regional observing network can be established using off-the-shelf components (Brown, 1983; Pratte and Clark, 1983). However, full utilization depends critically upon having carefully designed and implemented communications facilities to handle the sensor signals. Other problems include sensor failure due to weather and the need for highly skilled electronics technicians to maintain the equipment. For these reasons complex stations are usually placed near major population centres.

Given the remoteness of most of Canada's Atlantic Coast and the difficulties of siting and maintaining automatic equipment there, widespread use of unmanned weather stations to expand the observing network cannot be expected. Thus it is unlikely that forecast accuracy in marine areas can be improved in the near future by greater amounts of input land data. This picture could change if private forecasters in conjunction with offshore operators supplemented the AES network with additional equipment.

One example of how installation of an automated station reduced the information content in the observing network in the Atlantic Region was the loss of all sky and visibility data upon replacing the manned station at Cape Race, Newfoundland. This left a large segment of the coast with a reduced level of data pertinent to both air and vessel operations, that is detrimental, for example, to air-sea rescue activities in the area.

2.1.2 Ocean Weather Buoys

The deployment of ocean buoys to obtain meteorological and sea state data has increased greatly in recent years because of the loss of weather ships in the western North Atlantic and Pacific Oceans. The availability of

satellite-based communication systems has been very important in the development of buoy networks (Vockeroth and di Cenzo, 1982; Petrie and Lively, 1979; Hamilton, 1982; Schmidt and Zbar, 1983; Vockeroth et al., 1983).

While experience has been gained in eastern Canadian waters with both tethered and drifting buoys the problems presented by severe weather and ice in the first instance, and the short useful data acquisition period in the second, has inhibited their operational deployment. The key problems with small free-floating or tethered buoys include the vulnerability of the small platforms and sensor packages to weather damage, and the trade-off between the number and type of sensors with power requirements, deployment period and data amount for transmission. These problems are not easily overcome at acceptable cost, and for reliable data collection, much larger platforms (ships) are desirable. Thus it appears that ocean weather buoys have a low potential for extending the observing network offshore.

2.1.3 Shipboard Weather Stations

Two programs to gain reliable offshore data have recently been initiated. The first, based on the Argos data collection system (Vockeroth et al., 1983) is a program to equip eight vessels on the Canadian east coast with data platforms to provide air pressure and temperature information and, in some cases, to add keypads for the transmittal of manual observations. Such a system would have direct benefit to the east coast weather and wave forecasting programs.

The second, an automated shipboard aerological program (ASAP) (Cole et al., 1983) if operationally successful and if widely implemented would provide extremely valuable

upper air data in the vast data-sparse oceanic areas. More directly, perhaps, such a program could provide lower atmosphere winds and temperatures in the immediate offshore area which would be of great benefit to the forecast meteorologist.

Canadian scientists are deeply involved in the development of automated shipboard observing platforms, a situation which should provide early benefit to the offshore.

2.1.4 Wave Buoys

At present there are no wave measuring buoys dedicated to supplying data in real time in eastern Canadian waters other than Waverider buoys deployed near exploratory drilling rigs. Data from these instruments are recorded on the drilling vessel where they are interpreted by weather observers using MANMAR (AES, 1982) procedures. In general a significant wind sea height and period are obtained every three hours and transmitted to shore. Additional information on swell is also provided. These data are useful for initializing sea state prediction models but because they represent only point measurements are very limited for describing a wave field in space. Moreover, most of the data are clustered around centres of drilling interest -- Hibernia and Sable Island recently -- and thus do not present a uniform distribution of data points.

Most wave data collected near Sable Island is influenced by the island or the surrounding banks. This includes the effects of sheltering, refraction and shoaling. None of the wave prediction models presently in use (METOC and the private forecasters) explicitly takes these effects into account; thus, the Sable Island data must be used with extreme caution in conjunction with deep water wave prediction models.

Waverider buoys have been successfully modified to transmit wave data via satellite (L. Adamo, 1983, pers. comm.) and are routinely deployed for climatological studies in remote areas. Unlike Waveriders these new buoys compute a wave variance spectrum every three hours and transmit a set of energy density values. This allows one to recover the spectrum and calculate significant wave height and period from it. However, the original wave trace is lost in the compromise between minimum transmitted data, onboard storage and power/size requirements.

These buoys, like their weather counterparts, suffer from many of the same problems: they are disfunctional in sea ice, subject to spray icing in winter, with subsequent loss of data, and require periodic servicing. The tether/mooring systems can also fail with total loss of a rather expensive piece of hardware. In view of these problems, and limitations of the data, it is not expected that wave observing by means of buoys will expand significantly in the near future.

Of greater potential interest are techniques of remotely sensing the sea surface using SAR and radar altimeter sensors mounted on satellites. These provide a spatial description of the wave field over a short period of time which is, in principle, more compatible with initialization of wave prediction models. Realistically, operational data from satellites is at least 10 years away.

2.2 Instrumentation of Offshore Structures

When an offshore rig is moved into place in Canadian waters there is a commitment on the part of the operators to provide weather and sea state observations (COGLA,

1983). Instrumentation, observer training and program monitoring are AES responsibilities; observing practices are specified in detail in the MANMAR publication. As noted above for wave data, the meteorological parameters are also radioed ashore at regular intervals and enter the data distribution network. Like instrumented ships, these rigs provide a valuable extension of the observing network offshore.

The most critical of the meteorological installations is the wind anemometer which is placed as high as possible, usually on the derrick. This is in accord with current thinking (Dobson, 1980) on making the best possible measurements of marine winds. However, these anemometers are often very high ($\sim$60 m above MSL) and subject to wake effects caused by the structure. Current practice is to neglect the effects of flow distortion (a difficult problem even for simple structures), and the height of measurement, and to report the anemometer winds directly. A one-minute visual estimate of wind speed is made which is equated with the one-hour mean wind speed. Thus, because of differences in anemometer heights reported winds do not appear to be consistent within the offshore observing network.

The wind data are particularly valuable to the forecaster when preparing the analysis charts. The inconsistencies between rigs, and the winds reported from ships in transit, are recognized in a qualitative sense and broadly allowed for as the analyst deduces details of the weather system. Because of the large scale at which he works individual errors in wind speed, of perhaps as much as 20 percent of the wind at 10 m, tend to get smoothed out and don't contribute an equivalent error to final system description. As these procedures become more automated, however, this human judgement factor is in danger of becoming lost to the detriment of the final product.

Wind speed errors are of potentially greater concern to wave prediction schemes. Depending upon how models are re-initialized using marine wind fields, systematic errors in input winds may result in large systematic errors in predicted wave fields. The difficulty lies in the wave modeller not knowing what the available wind information really measures because of lack of information on the distribution network. As Canada moves into more enhanced wave prediction procedures (discrete spectral models) this lack of uniformity in reported marine winds will need to be rectified.

2.3 Satellite Imagery in Operational Forecasting

The ability to acquire and disseminate satellite images showing weather systems that cover substantial continental and oceanic areas (Figures 1 and 2) represents one of the major breakthroughs of modern meteorology. Their visual impact is enormous since they integrate widely dispersed point-observations into a whole picture showing the spatial structure of the atmospheric system, and their most common use has been and continues to be as a central aid to preparing synoptic analyses. As numerous authors (Pierson, 1983; Schmidt and Zbar, 1983; Vockeroth et al., 1983; Diehl et al., 1983) have pointed out, satellite imagery will continue to modify weather observing and forecasting practice; as it does so it is reasonable to expect forecast accuracy to improve over eastern Canadian waters.

Presently the use of satellite data in operational forecasting is based largely on imagery distributed by the Satellite Data Lab, Toronto and on the developmental work underway in Vancouver (Horita, 1981; Diehl et al., 1983). In the Atlantic Region the SDL imagery is regularly consulted in all offices but is done so visually as one

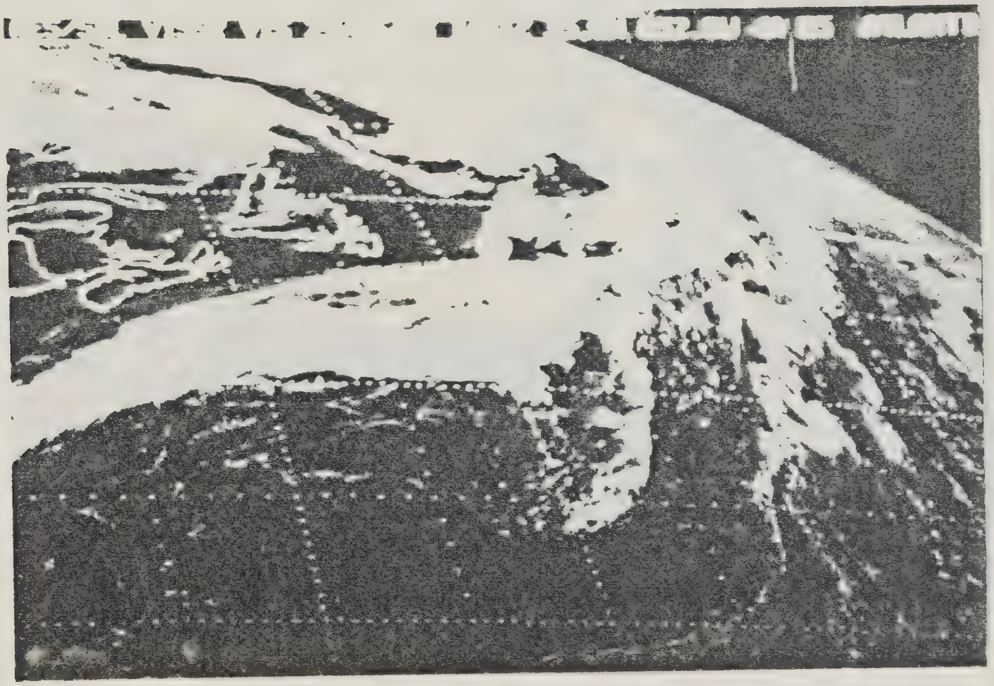

Figure 1. An unenhanced visual range GOES satellite image.

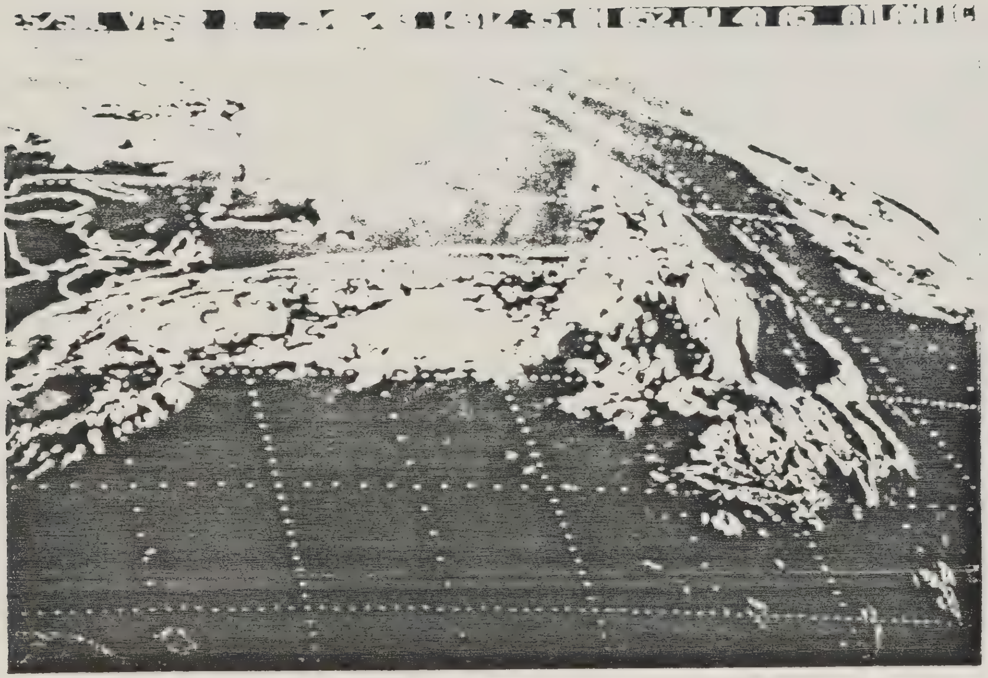

Figure 2. An enhanced infra-red range GOES satellite image.

source of data in preparing weather analysis and forecast charts. Effective means of quickly viewing successive photos are not available, a problem which is difficult to resolve due partly to a lack of hardware and financial resources.

It appears that one of the most powerful ways to take advantage of satellite imagery is, in fact, to be able to manipulate sequences of images by computer. In this way the meteorologist can see weather systems move, and change as they do so. It is the changes which are particularly important: they provide valuable insight into what to expect of the weather system as it evolves further, and thus are fundamental to prognosis. Obviously the lack of this type of equipment in Atlantic Canada must limit the weather forecasts issued there. However, it is not yet possible to quantify what constraints result, nor to estimate the end effect these have on exploratory drilling operations, if any.

2.4 Meteorological Scales

As data acquisition improves through better sensors, a denser network, and better communications, more detailed information on weather features becomes available. Research into the physical processes governing weather systems makes use of this information on different time and length scales. An understanding of these scales is fundamentally important to understanding meteorology, but is equally important to assessing the impact of weather and weather forecasting on offshore operations.

In the development of modern meteorology the charts upon which the simultaneously observed weather observations were plotted became known as synoptic charts and the study of the elements identified on the charts as synoptic

meteorology. The observations were gathered on land from stations which were seldom as close as 60 n.m. while over the oceans ship reports were usually much more widely separated. The familiar synoptic scale high and low pressure systems and fronts were identified on such charts.

As newer observational systems, including radar and satellite, became available and meteorological knowledge grew it became possible to identify smaller atmospheric features, usually interactive with the larger synoptic systems, that had an important bearing upon weather and sea conditions. The importance of the "mesoscale" in meteorology over the oceans and elsewhere has been recognized (Hewson, 1983a; Beran, 1983; Sanders, 1972b).

Three sub-scales of meso-meteorology have been identified (CMOS, 1983a, 1983b): (1) mesoscale α (200-2000 km, 1-3 days) weather fronts and extratropical cyclones; (2) mesoscale β (20-200 km, 2-24 hours) cloud clusters, rain bands, squall lines; (3) mesoscale δ (2-20 km, 0.5-2 hours) thunderstorms, internal gravity waves, urban effects. An upper limit of 1000 km has also been suggested for the mesoscale α dimension since this appears to provide a more comfortable relationship with the usual synoptic scale.

An earlier definition (Sanders, 1972b) assigns to the mesoscale those atmospheric phenomena smaller than the scale of the migratory high- and low-pressure systems (i.e. the synoptic scale) but larger than surface boundary layer phenomena. That is, the mesoscale is concerned with atmospheric entities which exist <u>between</u> meteorological stations or at least beyond the range of normal observation from a single point.

In any event, as the time and length scales decrease the phenomena of most interest are associated with increasingly intense events. In some respects the synoptic scale can be regarded as a kind of time/space average which smooths out the variability found at these mesoscales; presently, however, only the synoptic scale can be predicted with confidence. This is, perhaps, understandable when one considers how closely tied together the marine forecasting agencies are, both in terms of the common data bases used and their shared approach of forecasting over large oceanic areas from a central facility where the emphasis rests on synoptic weather trend prediction. If we consider the problem of predicting short-term (a few minutes to a few hours) changes in, for example, one-hour mean winds, gust winds, or heavy precipitation, at a particular rig location one can see that the present approach is incapable of responding.

The same situation is true also for sea state. METOC charts (Figure 3) provide only a "synoptic" description of the wave field that is by its appearance highly smoothed. Although the quality of sea state information may differ from the ocean-wide discrete spectral wave models (see e.g. Earle, 1981; Cardone and Ross, 1979; Golding, 1979) the spatial resolution is only a little better (by considering propagation effects crossing seas can be identified, but this is not routinely done). An example of a contoured significant wave height field produced by the U.S. Navy GSOWM model is shown in Figure 4. Present understanding of atmospheric variability is far better than our understanding of spatial variations in storm-generated wave fields; thus while one suspects predicted wave fields are smoothed like their atmospheric counterparts, there is little evidence to confirm or deny this contention.

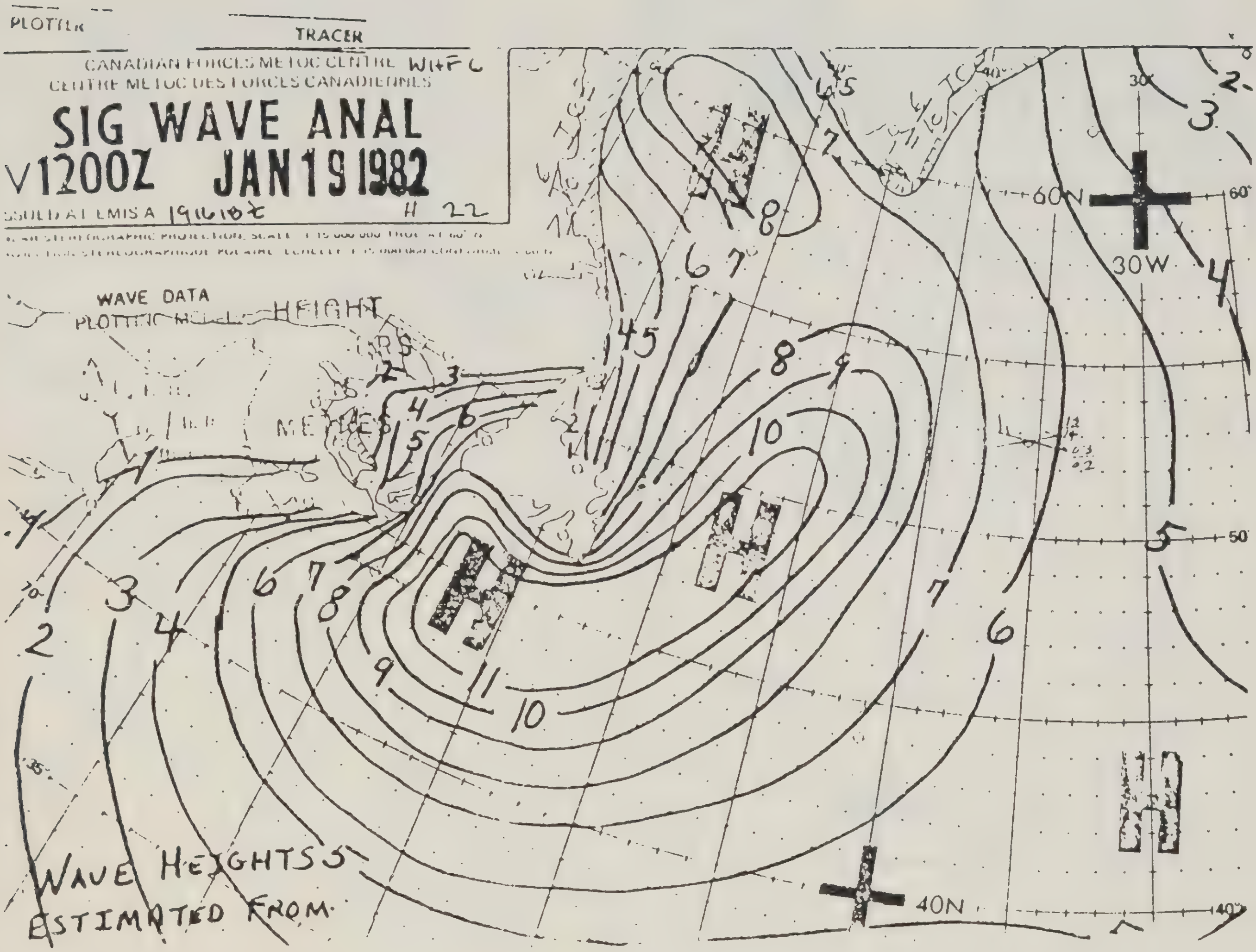

Figure 3a Example of a METOC significant wave height field presented on the analysis chart showing observed information.

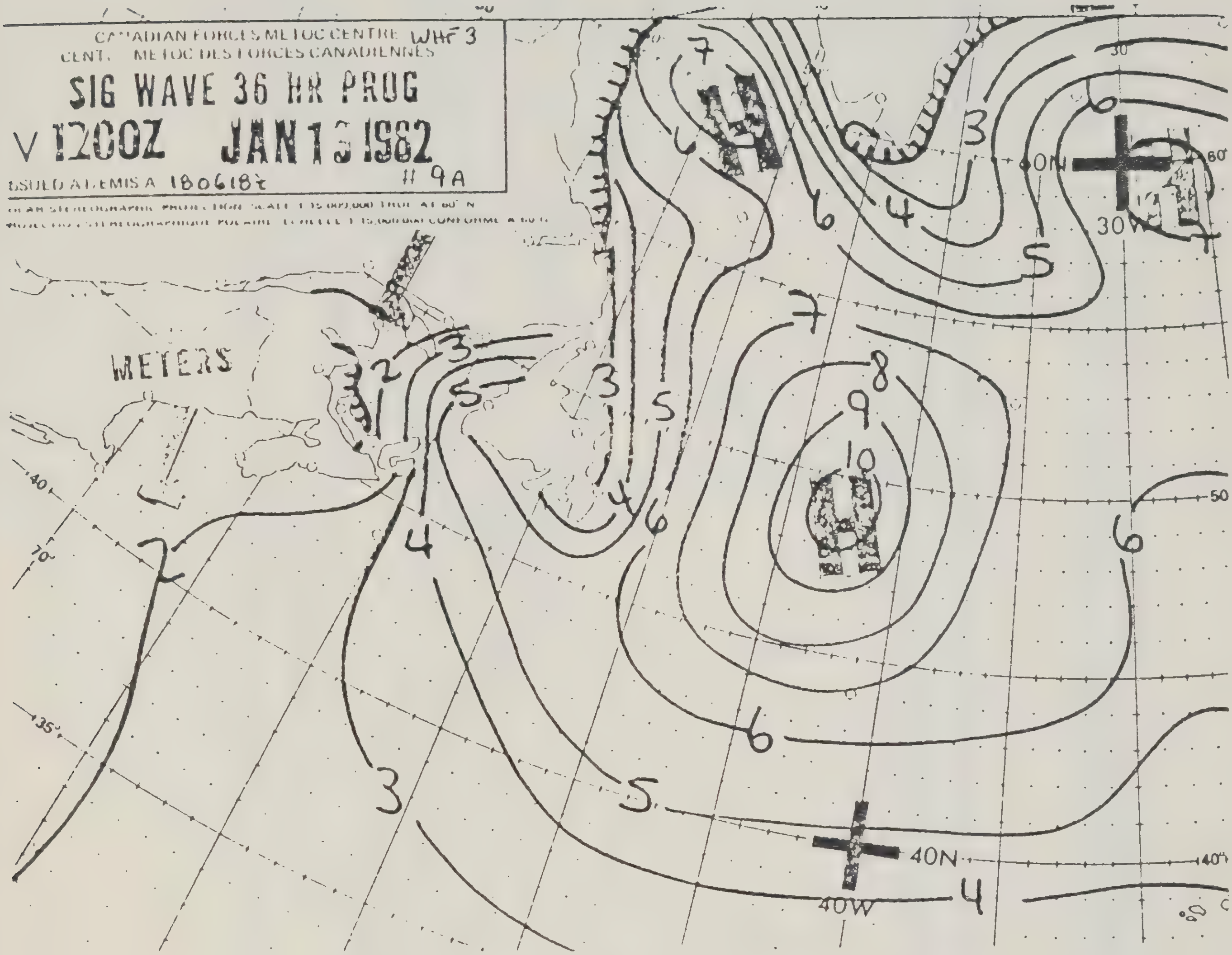

Figure 3b Example of a METOC significant wave height field predicted for 36 hours.

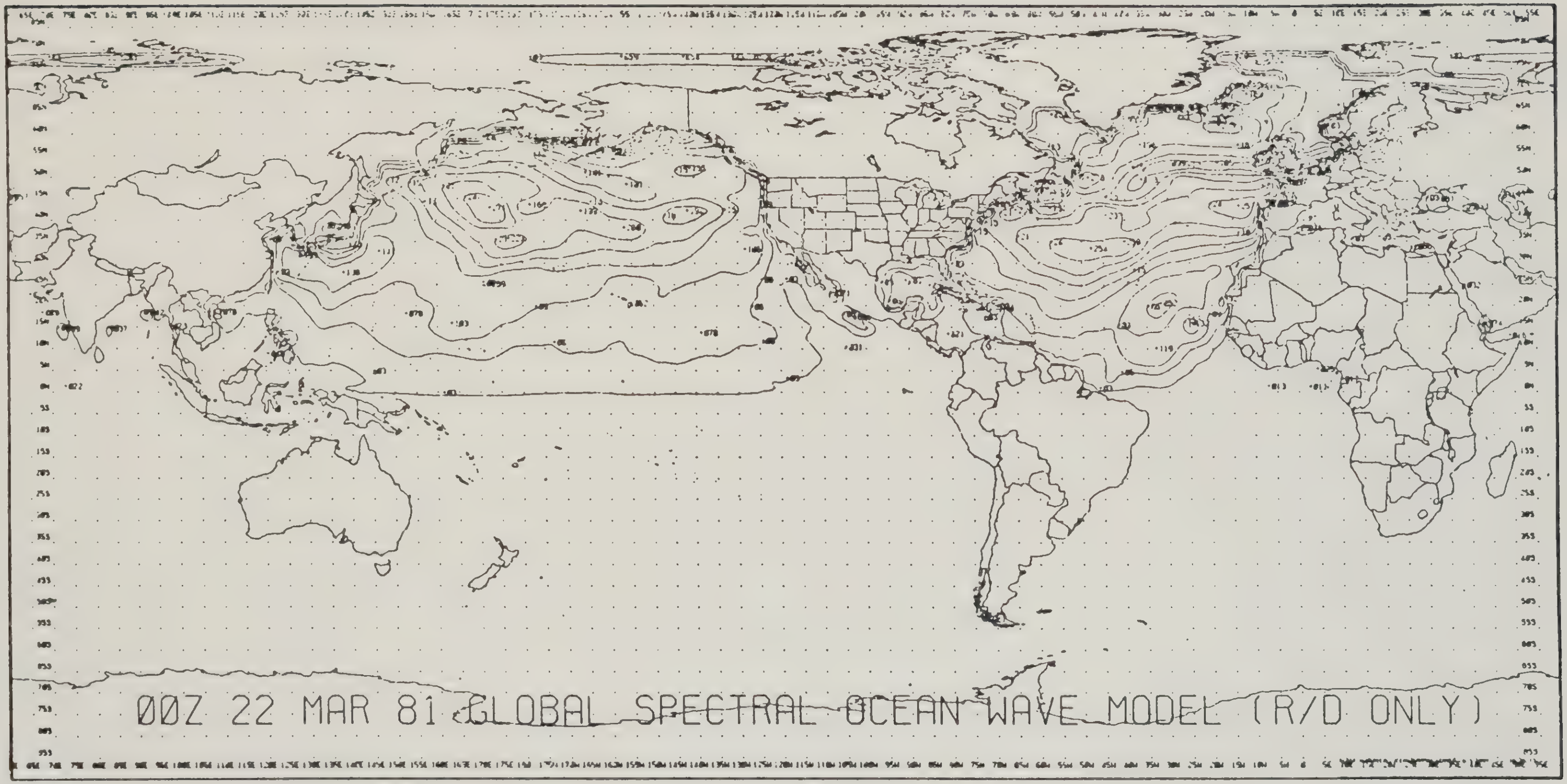

Figure 4 Example of a significant wave height field calculated by the US Navy GSOWM discrete spectral wave model. (Source: S. Lazanoff, FNOC, Monterey, Ca.)

This problem is made more difficult because significant wave height -- usually the key parameter that is forecasted for storms -- is a statistical measure of sea state intensity. While one can estimate the largest wave height associated with it by invoking yet more statistics, absolutely no information can be gained on wave grouping, the formation of episodic waves, or crossing characteristics which can lead to high, short-crested breaking seas.

3. EXTREME WEATHER CONDITIONS

There are several severe occurrences in meteorology which cause great concern to offshore operators in Eastern Canada. These are hurricanes, explosive deepening of atmospheric waves, certain mesoscale systems, freezing spray and unusually severe, crossing sea states. These are distinguished here from other synoptic-scale extratropical storm systems because they present the forecaster with extraordinary difficulties.

3.1 Hurricanes

In their formative areas over the warm waters of the southern North Atlantic tropical storms and hurricanes tend to be slow moving, but not necessarily easy to forecast (Wendland, 1977; Crutcher et al., 1982). Should one, in its degenerative phase, reach the eastern Canadian offshore it is usually moving much faster (Clark, 1983), but remains difficult to forecast. However, with the cooperation of American forecasters together with GOES satellite imagery, the chance of a hurricane arriving unannounced in Canadian waters has been effectively eliminated. Nevertheless they remain a very dangerous weather phenomena that tax the skills of forecasters dealing with them. The chief problems have to do with predicting the change in their pressure structure, and the trajectory of the low, as the system evolves. Both aspects directly affect the magnitude and persistence of peak winds and sea state at any particular location.

3.2 Explosive Deepening

Rapid cyclogenesis or deepening of storms moving generally from the southeast toward Canadian offshore waters occurs frequently, most often in the winter season. More than 20

such storms are found off the New England coast each year (Hayden, 1980) while on a monthly basis eight or so are observed to move toward Newfoundland (Bursey, 1977). Only a small number of these deepen explosively (Sanders and Gyakum, 1980) but enough do to present a difficult forecast problem. These storms have synoptic scales, are readily detected by the marine observing network and can be analyzed on synoptic charts; as noted above for hurricanes the difficulty lies in predicting the rate of change of central pressure in the low, which is very rapid, and its speed and direction of translation, both affecting the maximum wind speeds and wave heights at a site. They are not to be confused with mesoscale events that may escape early identification by passing between observation points at sea.

3.3 Mesoscale Events

There are certain situations when extreme winds are found in squalls or other similar small, intense storms over the ocean. Two examples can be described to illustrate the phenomena.

Sanders (1972a, 1972b) has discussed two sets of small-scale storms, about 10 hours apart, which formed as thunderstorms in a low pressure trough over Virginia and subsequently tracked out over the ocean disabling several racing sailboats in the June 1970 Bermuda Race as they did so. These storms were characterized by sustained 50-kt winds on their southeast side, and dynamically similar to tropical gales, tracked eastward at speeds of about 50 kt. They were so localized that at distances of about 80 n.m. away from the observations of gale force winds, peak gusts were observed no higher than 27 kt. Sanders (1972b) also describes the occurrence of a squall line, formed in conjunction with higher-than-normal sea surface

temperatures, in advance of a cold front associated with an intense cyclonic weather system originating in the Gulf of Mexico. As this squall line moved eastward over Florida and out to sea peak gusts of up to 100 kt were reported.

The other phenomenon, occurring in Arctic regions, is the "polar cold low"; these are responsible for many fish boat losses off northern Norway and have been studied there by Rabbe (1975). They have also been found in the Beaufort Sea (Hodgins et al., 1981; Hodgins and Harry, 1982) and in the wave hindcasting context by Hodgins (1983). These storms, comprised of cold air, form over ice or snow covered areas; as they migrate over the open ocean they absorb heat and this sets up strong convection leading to a small but intense cyclone. Gale force winds are commonly observed in these storms. In areas where the observing network is sparse, these systems can escape detection after they have formed, and are difficult to predict in advance of becoming established because little is known, as yet, of their dynamics and conditions of genesis.

These conditions are essentially unforecastable with present observing practices and prognostic methods focussed on synoptic scale systems. Even when they are observed, for example, in satellite images, forecasting their evolution is virtually impossible because of presently poor knowledge of their dynamic processes and their interaction with larger-scale circulations in which they are embedded. The major danger posed by these mesoscale events seems to be in the sudden increase in wind speed as they pass, and perhaps loss of visibility due to precipitation. Helicopter and supply boat operations are obviously susceptible to these rapid and localized changes in weather conditions.

3.4 Spray Icing

Because the necessary conditions of fast moving, very cold air over cold sea water occurs quite often along Canada's east coast, freezing of spray on boats presents a potentially serious hazard. As a response to the problem, the AES commissioned a study (Environmental Applications Group, undated) which reported on many aspects of the spray icing problem and reviews both subjective and objective methods available for forecasting icing occurrences. They have concluded that several of the recent numerical icing models (e.g. Kachurin et al., 1974; Stallabrass, 1980) could be implemented for routine forecasting use but that some improvements might be realized by incorporating attributes from several models into one predictive algorithm. The majority of icing models are based on a quasi-steady heat balance equation, and contain uncertainties in formulations of the physics in some terms, and in heat transfer coefficients in others; these shortcomings necessarily limit the accuracy of predicted ice acretion rates. But, from a forecasting standpoint prediction of the hydrometeorological conditions likely to produce vessel icing remains the key problem. Spray icing depends upon knowing low-elevation winds, air temperatures, sea water temperatures, wave conditions and information on the vessel, its heading, speed and basic configuration. Under circumstances where these conditions have subsynoptic scales, their prediction is very tenuous at best, and the use of physically-based deterministic models would be unwarranted.

3.5 Crossing Seas

Crossing seas refer to conditions where waves propagating in two different directions intersect to form short-crested, steep, breaking seas. These are particularly

dangerous for small craft operation, including search and rescue and emergency evacuation. They are produced in three ways: combinations of swell and locally generated wind seas, refraction by bathymetry (West Bar of Sable Island is notorious) and refraction and shoaling by ocean currents.

The most important case of the first cause is associated with severe east coast weather systems that move northeastward more rapidly than the phase speed of the large waves they generate. These storms can, for example, outrun large waves formed on the Scotian Shelf, and if they slow down over the Grand Banks create locally severe seas there which within a few hours begin to feel the Scotian Shelf waves that have propagated along behind the storm. These "swell" waves will have long periods ($\sim$15 to 20 s) and will generally have a different mean direction than the locally generated wind sea. Each system of waves will contain substantial energy and the combined crossing sea states will be irregular and, perhaps, rather severe in terms of vessel behaviour.

Clearly, formation of such sea states depends upon the character of an individual storm and the particular trajectory it follows up the Atlantic seaboard. The level of meteorological detail required to predict and describe these conditions goes well beyond wave forecasts routinely prepared now with parametric significant wave height models. It would be possible to simulate the generating processes using discrete spectral wave models coupled to large scale numerical wind models but this is not presently done in Canada.

Crossing seas produced by refraction, either depth or current induced, are localized phenomena, often well known to fishermen, but with scales too small to be considered

forecastable. The basic physics describing these processes is well enough known to construct mathematical models that could be used for prediction. However, in common with many other aspects of meteorological modelling, there is still sufficient uncertainty that more research, and particularly field data, is required to yield procedures suitable for routine forecasting use.

4. FORECAST PREPARATION AND PRESENTATION

In the last two chapters we have reviewed some recent developments in data acquisition that, in principle and/or in practice, serve to upgrade present-day forecasting, and we have discussed some examples of severe weather that are either unforecastable, or because of special features, give forecasters difficulty and lead to prediction uncertainty. We have drawn attention to the fact that on occasion the severest weather is associated with subsynoptic, or mesoscale events, that have short time scales and are very localized. In this chapter we shall comment on some aspects of how forecasts are prepared and presented to end users.

4.1 Preparation

The weather and sea state forecast, warning, and information services to the eastern offshore regions of Canada are supplied by AES and private contractors. The relationship of these organizatons is discussed in Part I of this report. For a given area no less than four forecasters may be immediately involved: the AES marine and airways forecasters, the CFWO sea state forecaster, and the forecasters of private companies writing site specific, route or even area weather and sea state forecasts for clients within the AES area of responsibility. In addition personal briefing services into the area are offered from conveniently located presentation offices or through the forecast offices themselves. When it is further recalled that these specialists are supported by the staffs of the Atlantic Weather Central and Canadian Meteorological Centre in Canada, and to a degree by the staff of the National Meteorological Center and the Hurricane Forecast Center in the United States, the rather considerable resources

devoted to the solution of offshore meteorological and sea state problems may be realized.

Because of the large size of this system, there exist redundancies in data dissemination and prognosis services which may work to the detriment of users. The following comments summarize our own opinions and findings from this study, along with those of others, in the area of forecast preparation. No attempt is made here to describe forecasting methods; this is a subject far too specialized and extensive to be addressed in the present report.

1) Pender (1983) argues that too much numerical guidance is available to forecasters at the operational level and that it would be more efficient and just as effective if only the best prognostic solution, instead of several options, were presented to the duty forecaster. Studies by CMC meteorologists (Gladstone, 1981; Boucaud, 1982) appear to support this view. This reflects the large volume of material disseminated by CMC and the regions to the staff meteorologist who must make the area forecast.

2) The Canadian Air Transportation Administration in the Atlantic Region requires that the AES issue site specific rig forecasts as well as area forecasts when helicopter operations are involved. In the summer of 1983 this required the NWO airways forecaster to issue as many as three area forecasts and seven rig forecasts in addition to his regular airways commitment. Dissemination of this many forecasts, which are duplicated by other agencies, tends to degrade the information content of the forecast presentation simply because local personnel are left without sufficient time for analysis.

3) The forecast service provided under contract to offshore operators by private companies follows

established guidelines (COGLA, 1983) and is well organized (see e.g. NORDCO, 1983). Forecast structure and terminology is well defined and verification procedures are documented. However, a lack of formal, internal prognostic procedures as a basis for forecast decisions that extend some distance into time (e.g. 36 to 42 hours) appears to be a program weakness.

4) Although forecast services have been developed on an hierarchical basis it is very difficult to effect useful discourse between forecasters at various levels when a difference of opinion exists (Pender, 1983). Thus problems may go unresolved, and the combined wisdom of several experienced analysts seldom gets applied to difficult situations to forecast. In many cases these may involve severe weather.

5) The lack of direct contact between the forecaster and the user also is a service weakness. The utilization of graphics to improve presentation may better the situation, as may the establishment in companies with larger offshore operations of "environmental operations centres" to provide the interface between the forecast service and the ultimate user.

4.2 Presentation

The forecast meteorologist must reduce the complex three-dimensional, dynamic atmosphere and its evolution out to about 48 hours, down into a few easily comprehended parameters so that he can communicate his forecast to intended users. Over the years a plain language procedure has been developed by AES, describing weather systems (lows, gales, storms) and key parameters (wind, snow, rain, fog, visibility, temperature and freezing spray) essentially for public consumption. Examples of marine

area weather forecasts and weather warnings, issued by NWO (AES) are shown in Figure 5. These messages are useful to mariners who serve an apprenticeship at sea, and who through experience come to learn what these outlooks mean in terms of their own craft and activities.

Clearly these prognoses do not attempt to give information on wind speed, temperatures, or visibility, that resemble the detailed history of an event, or what one would measure with an instrument during the valid period. This is indicated by the very fact that AES does not attempt to define the forecast parameters in a mathematical way, e.g. defining wind speed as a time average over a specific period. Rather these parameters are indicators of what to expect for severe marine conditions during the valid time.

Similar information, abbreviated yet more, is provided in the AES (NWO) aviation and rig terminal forecasts. An example is shown in Figure 6. These forecasts are unintelligible to the non-specialist. They do not provide much more information than the marine area forecasts and hence contain weather parameters having the same meaning.

Private agencies, but particularly NORDCO (1983), have attempted to present forecasts in a more precisely defined manner. This has been done in two ways: by carefully defining what individual weather parameters mean, mathematically where possible, and by the presentation format. The parameters used by NORDCO, by way of an example, are shown in Table 1. An added element of precision is included by attempting to forecast wind speed and direction parameters at the anemometer elevation on the rig; this enables quick comparisons between predicted and measured winds during normal operations.

The format of NORDCO's forecast for specific rigs is

FPCN20 CYQX 031530
PART 1 OF 2
OFFICIAL NEWFOUNDLAND MARINE FORECAST ISSUED BY ENVIRONMENT CANADA FROM THE GANDER WEATHER OFFICE AT NOON NST ON THURSDAY 03 JANUARY 1980 FOR TODAY AND FRIDAY.

BELLE ISLE
BELLE ISLE BANK.
STORM AND FREEZING SPRAY WARNINGS CONTINUED.
WINDS LIGHT INCREASING TO NORTHEASTERLY 20 KNOTS THIS EVENING AND TO NORTHEASTERLY GALES 35 TO 45 TONIGHT. NORTHERLY GALES 45 TO 55 ON FRIDAY. VISIBILITY LOWERING TO FAIR IN SNOW BY THIS EVENING. FREEZING SPRAY DEVELOPING TONIGHT. TEMPERATURES MINUS 5 TO MINUS 10.

HARRINGTON
WEST COAST.
STORM AND FREEZING SPRAY WARNINGS CONTINUED.
NORTHEASTERLY WINDS 20 KNOTS INCREASING TO NORTHERLY GALES 35 TO 40 THIS EVENING AND TO NORTHWESTERLY GALES 45 TO 55 FRIDAY MORNING. VISIBILITY GOOD LOWERING TO FAIR IN PERIODS OF SNOW THIS AFTERNOON. FREEZING SPRAY DEVELOPING TONIGHT. TEMPERATURE NEAR MINUS 3 FALLING TO MINUS 10 OVERNIGHT.

SOUTH COAST
EAST COAST
FUNK ISLAND BANK
NORTHERN GRAND BANKS.
STORM WARNING CONTINUED.
FREEZING SPRAY WARNING CONTINUED FOR COASTAL WATERS.
EASTERLY WINDS 25 TO 30 KNOTS INCREASING TO NORTHEASTERLY GALES 35 TO 45 BY THIS EVENING AND TO NORTHWESTERLY GALES 45 TO 55 FRIDAY MORNING. VISIBILITY FAIR IN RAIN AND SNOW AS" POOR IN FOG PATCHES TODAY. FAIR IN PERIODS OF SNOW ON FRIDAY. FREEZING SPRAY DEVELOPING OVER COASTAL WATERS FRIDAY. TEMPERATURES MINUS 2 TO PLUS 3 TODAY FALLING TO MINUS 2 TO MINUS 8 ON FRIDAY.

END PART ONE.

Figure 5 Marine weather forecast issued by the Newfoundland Weather Office of the AES.

WWCN1 CYQX 261330
WIND WARNING FOR EAST COAST OF NEWFOUNDLAND AND WEST COAST DANIELS HARBOUR AND NORTH ISSUED BY ENVIRONMENT CANADA AT 1100 AM NDT SATURDAY 26 SEPTEMBER 1981.

A LOW CENTERED NORTHEAST OF CAPE FREELS THIS MORNING WILL CONTINUE TO INTENSIFY AS IT MOVES NORTHEASTWARD. STRONG NORTHWESTLY WINDS HAVE DEVELOPED BEHIND IT AND ARE EXPECTED TO CONTINUE TO STRENGTHEN OVER NORTHERN AND EASTERN AREAS THIS AFTERNOON. GUSTS TO 100 KM/H CAN BE EXPECTED IN EXPOSED AREAS ON THE EAST COAST AND NORTHERN PENINSULA BY THIS EVENING. THE WINDS WILL DIMINISH SLOWLY ON SUNDAY AS THE LOW MOVES FARTHER AWAY.

END

WWCN1 CYQX 261310
STORM WARNING FOR BELLE ISLE EAST COAST BELLE ISLE BANK FUNK ISLAND BANK AND THE NORTHERN GRAND BANKS MARINE AREAS ISSUED BY ENVIRONMENT CANADA AT 1040 AM NDT SATURDAY 26 SEPTEMBER 1981.

A LOW CENTERED NORTHEAST OF CAPE FREELS THIS MORNING WILL CONTINUE TO INTENSIFY AS IT MOVES NORTHEASTWARD. NORTHWESTERLY GALES HAVE DEVELOPED BEHIND IT AND ARE EXPECTED TO CONTINUE TO STRENGTHEN OVER NORTHERN AND EASTERN WATERS TO REACH STORM FORCE BY THIS EVENING.
THE GALE WARNINGS HAVE BEEN UPGRADED TO STORM WARNINGS OVER BELLE ISLE EAST COAST BELLE ISLE BANK FUNK ISLAND BANK AND THE NORTHERN GRAND BANKS MARINE AREAS.
MORE DETAILS WILL BE CARRIED IN THE NOON NEWFOUNDLAND MARINE FORECAST.

END

WWCN1 CYQX 252233
GALE WARNING FOR SOUTH COAST EAST COAST AND ALL GRAND BANKS MARINE AREAS ISSUED BY ENVIRONMENT CANADA AT 0803 PM NDT FRIDAY 25 SEPTEMBER 1981.

A LOW NEAR THE BURIN PENINSULA IS EXPECTED TO DEEPEN AS IT MOVES NORTHEASTWARDS ACROSS THE ISLAND TONIGHT. NORTHWESTERLY GALES DEVELOPING BEHIND THE LOW ARE EXPECTED TO AFFECT ALL NEWFOUNDLAND WATERS BY MORNING. DETAILS ARE GIVEN IN THE REGULAR MARINE FORECAST.

END

Figure 6 Marine weather warning issued by the Newfoundland weather Office of the AES.

MS
282
FACN3 CYQX 171145 AMD

12-24

HGTS ASL UNLESS NOTED

PROG
NE-SW COLD FNT 60 E CAPE RACE AT 12Z MOVG EWD 10 KTS AND WKNG.
RGNS IN MDT-STG SWLY FLO E FNT BCMG MDT WLY FLO W FNT

FLEMISH
CLDS AND WX. WITHIN 80 FNT 0-8 OVC 60+ 0-2RW-F FEW CB GVG TRW-
NR FNT. BYD 80 NW FNT 10-20 BKN 60 FQT ST CIGS 1-5 VSBYS 1/2-3F

ICG. NONE BLO 60. FRLVL 120

TURBC MDT-SVR VCNTY CB

WINDS 3-2325 6-2325

SEA STATE NR 2 METRES

END

PROG
NE-SW COLD FNT HOPEDALE AT 12Z MOVG TO BATTLE HARBOUR AT 24Z.
SE FNT MDT SLY FLO BCMG MDT-STG NWLY FLO NW FNT

HARRISON BANK NAIN BANK RGNS
CLDS AND WX. WITHIN 120 E FNT AND 60 W FNT CIGS 20 BKN V OVC 60+
2-6RW-F FEW CB NR FNT GVG TRW-. BYD 60 W FNT 20 BKN OCNL OVC 60
OCNL RW-. FQT ST CIGS 5-10 VSBYS 1-3F OVR SEA E OF FNT

ICG. NONE BLO 60. FRLVL 120 LWRG TO 60 100 MI NW FNT

TURBC MDT-SVR VCNTY CB

WINDS SE FNT 3-2520 6-2520 NW FNT 3-3230 6-3230

SEA STATE NR 1 METRE

END K

MS
282
FTCN2 CYQX 171130
RIG TERMINAL FORECASTS
SEDCO 706 171221 C0 X 0F 2425 VRBL C3 OVC 1RW-F RISK 1TRW-F
ZAPATA UGLAND 171221 C0 X 0F 2325 VRBL C3 OVC 1RW-F RISK 1TRW-F
WEST VENTURE 171221 C0 X 0F 2325 VRBL C3 OVC 1RW-F RISK 1TRW-F
SEDCO 710 171221 C0 X 0F 2420 VRBL C3 OVC 1RW-F RISK 1TRW-F
PACNORSE 1 171221 C20 BKN 3125 OCNL RW-
PELERIN 171221 C20 BKN 3125 OCNL RW-
NEDDRILL 2 171221 C20 OVC 2225 OCNL C5 OVC 1RW-F RISK 1TRW-F. 13Z
C20 BKN 3125 OCNL RW-

Figure 7. Aviation and rig terminal forecasts issued by the AES.

Table 1

Weather and Sea State Parameters used by NORDCO Ltd. In Their Forecasts

PARAMETER NAME	METRIC UNITS	IMPERIAL UNITS
Wind Direction	°true	°true
Wind Speed	metres/second	knots
Maximum Wind Speed	metres/second	knots
Maximum Gust or Squall Speed	metres/second	knots
Significant Sea Height	metres	feet
Maximum Sea Height	metres	feet
Sea Wave Period	seconds	seconds
Primary Swell Height	metres	feet
Secondary Swell Height	metres	feet
Primary Swell Direction	°true	°true
Secondary Swell Direction	°true	°true
Primary Swell Period	seconds	seconds
Secondary Swell Period	seconds	seconds
Significant Combined Sea	metres	feet
Maximum Combined Sea	metres	feet
Air Temperature	°C	°F
MSL Pressure	millibars	inches Hg
Visibility	metres	nautical miles
Sky Cover	tenths	descriptive terms
Weather and Obstructions	N/A	N/A
Freezing Spray	cm/day	descriptive terms

illustrated in Figure 8. Following an identification header, plain language warnings can be given as appropriate. Weather parameters are specified next in tabular format under valid times given to specific hours local time. A plain language synopsis describing long range trends can also be included.

It is worth noting that NORDCO defines the mean wind speed to be a 6-hour average representative of the valid period of the forecast. The maximum wind speed is interpreted as the highest value of the one-minute means measured at the anemometer and read every one or three hours.

4.3 Comments on Presentation

The amount of information contained in the above presentation formats is extremely low for the non-specialist user, i.e. for persons without a knowledge of meteorology. As already noted earlier, all forecasting agencies have a very symbiotic relationship since they all receive the same information, over the same networks, and use much the same forecasting methods. As a result their forecast products are similar also and approach the description of weather, present and future, the same way. Because meteorological practice focusses on the synoptic scale, and essentially tries to ignore subsynoptic scale effects, the apparent lack of definiteness, or "precision," in forecast parameters may in fact be entirely justified. The format adopted by the private forecasting agencies appears more scientific and may, as a result, imply a precision (e.g. in wind speed or wave height) which is not really there since their procedures differ little from those of AES with respect to mesoscale phenomena. This point will be discussed further following forecast verification in the next chapter.

```
45848
SEDCOT06 SNF


NORDCO SNF
TIME OF ISSUE 01 0500Z

FORECAST FOR THE ZAPATA UGLAND AND THE SEDCO 706 ISSUED BY NORDCO LTD
FOR MOBIL OIL CANADA AT 0230 NDT SATURDAY, MAY 01, 1982 VALID UNTIL
2130 NDT SUNDAY WITH AN OUTLOOK FOR THE NEXT THREE DAYS.

WARNINGS IN EFFECT...NONE

VALID TIME     01/12Z  01/18Z  02/00Z  02/06Z  02/12Z  02/18Z  03/00Z
NDT            0930    1530    2130    0330    0930    1530    2130

WIND AT ANEMOMETER
DIRECTION      130     130     130     140     140     140     140
SPEED          28      25      20      20      20      18      15
MAX SPEED      32      30      30      25      25      25      22

SEA WAVE
SIG HEIGHT     6       6       5       5       5       4       4
MAX HEIGHT     10      10      9       9       9       7       7
PERIOD         5       5       5       5       5       5       5

SWELL WAVE
DIRECTION      120     120     120     120     120     120     120
HEIGHT         5       6       7       7       7       6       6
PERIOD         9       10      10      10      11      11      10

SKY            OBSCD OCNL OVC THRUT
AIR TEMP       4       5       6       4       4       5       6
VISIBILITY     1/8-1/2 OCNL 1-3 THRUT
WEATHER        FOG,OCNL L- AND MIST..................................

OUTLOOK VALID 00Z MONDAY TO 24Z WEDNESDAY

MON  WINDS SE TO S 10-20, VSBY POOR, MCS 10 FT
TUE  WINDS SWLY 5-15, VSBY FAIR/POOR, MCS 9 FT
WED  WINDS SWLY 5-15, VSBY FAIR/POOR, MCS 9 FT

SYNOPSIS:
        A NEAR STATIONARY FILLING LOW OVER THE MARITIMES COMBINED
WITH A STATIONARY HIGH PRESSURE AREA COVERING THE CENTRAL NORTH
ATLANTIC IS EXPECTED TO MAINTAIN A GENERALLY STRONG SOUTHEASTERLY
FLOW OF MILD MOIST AIR THRU THE FORECAST PERIOD.  NO SIGNIFICANT
CHANGES FROM THE PRESENT CONDITIONS ANTICIPATED TODAY OR SUNDAY.

THE NEXT REGULAR FORECAST WILL BE ISSUED AT 01 1000Z

END

18
SEDCOT06 SNF

NORDCO SNF
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Figure 8 Example of a NORDCO forecast for two rigs on the Northern Grand Banks.

Given the level of electronic technology used on exploratory drilling units, these simple parametric descriptions of weather elements, transmitted verbally and by teleprinter, seem surprisingly unsophisticated. Colour graphic displays of spatial/temporal changes in weather, related to wind and sea state parameters geared directly to downhole, supply and helicopter operations, and integrating real-time measurements (ice and weather radars, long-range wave measurements) are realizable with present technology. However, the relevance of the increased information levels in this type of approach, to decision makers involved in the hour-by-hour drilling operations, needs to be carefully appraised. This is fundamental to assessing the adequacy of the present, or any forecasting system.

5. FORECAST VERIFICATION

At the end of Chapter 2 the notion of meteorological scales, in both space and time, was introduced for the purpose of classifying severe weather. Examples of such weather, important for drilling operations offshore, were then described briefly, and methods of forecast presentation covering these and other events were discussed. It was pointed out in the last chapter that forecasts prepared both by the national and regional AES agencies, and by private forecasters, tend to deal with comparatively long-term averages of the expected conditions. Setting aside for the moment the limitations these averages may impose on interpreting the forecast at the rig, it is relevant to examine what response each agency takes to verifying its forecasts, and what level of performance can be expected of the forecast.

The perspective adopted here is how well do the forecasts predict peak storm response -- of wind and wave heights, for example -- and do the verification techniques give this measure of performance.

5.1 Some Historical Background

With the establishment of the new Aviation and Public Weather programs in Canada in the early years after World War II, verification programs were set up to monitor results. Both provided numerical ratings of forecasts which, hand-done, were costly to maintain and, as a result, were abandoned in the early sixties. The programs were not particularly effective for they contained a good deal of fair weather bias and did little to focus attention on continuing forecast problems.

When Central Analysis Office (now CMC) was organized in

the mid-fifties, an S-1 program (Teweles and Wobus, 1954) was put in place. This system measures the accuracy of prognostic chart construction. Although it also was originally done by hand it is now computerized.

In the Atlantic Region some verification has been continued, for example monitoring St. John's and Gander aviation forecasts by NWO, while at AWC S-1 scores have been plotted for about 13 years. More recently their S-1 scores have been graphed as a means of comparing the results of objective and subjective prognostics.

Nationally, AES has reintroduced verification of both aviation and public forecasts (AES, 1983b) as a means of assessing product usefulness. However, it is too early to estimate how effective this program will be.

As a result of offshore developments in Canada it is now manditory to verify wind and sea state forecasts (COGLA, 1983). Verification of the 1982 Beaufort Sea program provides one example (AES, 1983c), where in addition to the numerical verification analyses, attention is also directed to synoptic descriptions of storm winds observed in the Beaufort Sea.

Other examples, on the east coast, are the verifications carried out by NORDCO Ltd. of their own forecasts (NORDCO, 1983), which will be discussed in more detail below, and the Scotian Shelf forecasts provided by MacLaren-Plansearch to Mobil Oil Canda, Ltd. These latter forecasts are being verified by the MEP Company in Toronto; however, documentation on methods and results was not available at the time of this study.

5.2 Severe Weather Verification

5.2.1 By the AES

This review has found that the AES is doing relatively little to verify their forecasts of severe weather. There have been useful studies in the past (Bursey et al., 1977) and while this kind of work is encouraged within AES, rather few regional resources are available for the purpose. The need for verification is recognized (Pearce, 1983; AES, 1983d) not only to assess performance after tragedies (Richards, 1982; Cardone, 1982) but also when severe weather that has been forecast does not occur. User confidence can be undermined by "overforecasting" perhaps as readily as by "underforecasting." Therefore it is considered important to study not only those systems that (1) were expected to cause severe weather and sea state conditions and did, and (2) were not expected to and did, but also (3) those that were expected to and did not.

Studies of storms in these three categories, examining both their time-series characteristics (e.g. of pressure, wind speed and direction, and precipitation) at a point and their synoptic aspects (descriptive), would provide forecasters with the necessary background to infer change more successfully in the early stages of storm development. The result should be improved Day-1 forecasts at a minimum. However any program of this type must necessarily take resources away from active forecasting, and this is difficult to achieve within the present framework of regional services in the AES.

Verification of Northern Grand Banks marine wind forecasts by the Gander Weather Office (Porter, 1983, pers. comm.) has been attempted for 1982. All weather was considered, not just severe events, and a correct forecast of wind

speed was defined by agreement within ±5 knots. Direction was not examined. Two lead times were also considered: out to 21 hours, "today," and out to 45 hours, "tomorrow." The results are shown in Table 2 and indicate that correct predictions are achieved just over half of the time (55%); of the balance, 19% are overforecasted and 26% are underforecast. This last figure is interesting in that it shows forecast errors to be biased low and that actual winds were stronger than predicted by about 7% of the incorrect prognoses. By not concentrating on severe events there is no way to tell if the majority of incorrect forecasts, or the underestimates of wind speeds, were connected with storm systems. In many respects this limits the utility of the verification from the perspective of this study. The data also show that there is a small overall score improvement for the shorter lead time (6%), and a somewhat greater improvement (12%) for underforecast winds.

Table 2

AES Forecast Verification for the Northern Grand Banks

Gander Weather Office - 1982

Category	Today	Tomorrow	Total
Correct	57.7%	51.5%	54.6%
Over Fcst by 5 kts	16.6%	9.9%	13.2%
Under Fcst by 5 kts	13.5%	19.9%	16.7%
Total Over Fcst	21.9%	16.1%	19.0%
Total Under Fcst	20.5%	32.5%	26.5%

Source: S. Porter, NWO (1983)

5.2.2 By NORDCO

NORDCO forecasts are verified on a well-by-well basis for their industrial clients in two ways: first, in terms of absolute accuracy giving error estimates for individual prognoses, and second using a reliability index (Hewson,

1983b) designed as a measure of forecast utility based on correct forecast scores. The first approach, dealing with absolute error of the forecast data product, is the more relevant for assessing how well peak conditions are predicted. The reliability index as computed by NORDCO, while it may be useful for guidance, suffers from rather coarse discrimination of events to be useful for assessing performance in the sense used here. This is illustrated in the following classification, extracted from NORDCO (1983), for severe weather events:

	Event Number				
	5	6	7	8	9
Windspeed (knots)	28-30 (2)	34-40 (6)	41-47 (6)	48-63 (15)	>63 open
Combined Wave Heights (m)	3.4-4.8 (1.4)	4.9-6.5 (1.6	6.6-7.9 (1.3)	8.0-11.3 (3.3)	>11.3 open
Wave Period (s)	11.5-17.0 (5.5)	17.5-24.0 (6.5)	>24 open	-	-
Wind Direction (°T)	45-degree sectors				

(Numbers in brackets give the increment of each event.)

The ranges have the property of <u>decreasing</u> resolution with <u>increasingly severe</u> weather; this may, in fact, reflect a forecaster's ability to predict storm weather parameters, and so be consistent with meteorological practice, but it is less clear that it serves the intended offshore user so well.

Error figures presented by NORDCO (1983) for the Nautilus C-92 well drilled by Mobil Oil Canada, Ltd. have been examined in this study. They were derived from

differences between the forecast data product and the MANMAR rig measured data. The observed data were correctly averaged for comparisons of mean wind speed and wave height. Comparisons of maximum sustained wind speed were made with the largest observed value in the 6-hour period bracketing the valid time of the forecast.

The statistical summary of errors for both mean and maximum wind speeds for all observations is shown in Table 3 for lead times of 6 to 42 hours in 6 hour increments. The mean wind predictions, within ±5 knots agree well with Gander Weather Office results (Table 2) showing that out to 24 hours about one half of the prognoses are correct. This figure goes up to 65% when the maximum wind speed is used in place of the mean wind speed. Unlike AES however, NORDCO show a bias to overforecasting winds when they are in error outside of the 10 knot tolerance. Of the incorrect forecasts, overforecasts are in a ratio of about 3:1 to underforecasts, roughly true for either mean wind or maximum wind speeds.

The same statistics are reported for maximum speeds in storm force winds and separately for speeds exceeding 60 knots (Table 4). In these severe event categories, wind speed predictions within 10 knots are achieved just under one half the time (43%) for storm force winds, but only about 20% of the time for speeds over 60 knots. We find, however, that in the NORDCO severe event forecasts over-estimates of wind speed occur between 80 to 90% of the time that any error is made, which gives predictions on the "safe side" in the engineering sense.

Similar statistics are given for combined sea height in Table 5. Out to lead times of 12 hours an approximately 50% success rate is achieved for heights between 5 and 8 m using an accuracy criterion of ±0.5 m. For heights above

Table 3

Statistical Summary of Mean and Maximum Wind Speed Forecast Accuracy - All Winds

WELL HEAD : NAUTILUS C92
VESSEL : SEDCO 706
LAT/LONG : 46.9N 48.7W
PERIOD : SEP 24 1981 - JUL 16 1982

TABLE NUMBER 5 : MEAN WINDSPEED FORECASTS OF STORM FORCE

LEAD TIME	6	12	18	24	30	36	42	HOURS
SAMPLE SIZE	45	37	35	28	26	22	8	NUMBER
MEAN ERROR	8.9	9.8	9.8	9.4	8.1	6.0	4.5	KNOTS
MEAN ABSOLUTE ERROR	10.1	10.7	11.2	11.1	10.2	9.8	8.5	KNOTS
MEAN RMS ERROR	12.6	13.4	13.3	13.2	12.5	11.6	8.9	KNOTS
UNDERFORECASTS	15.6	10.8	14.3	17.9	15.4	22.7	25.0	PERCENT
MEAN UNDERFORCASTS	3.9	4.3	5.0	4.8	7.0	8.4	8.0	KNOTS
LARGEST UNDERFORECAST	7	6	6	7	10	11	9	KNOTS
OVERFORECASTS	77.8	83.8	82.9	78.6	80.8	77.3	75.0	PERCENT
MEAN OVERFORCASTS	12.2	12.2	12.7	13.0	11.3	10.2	8.7	KNOTS
LARGEST OVERFORCAST	34	34	34	30	29	27	15	KNOTS
% WITHIN 5 KNOTS	28.9	27.0	22.9	17.9	23.1	22.7	0.0	PERCENT
% WITHIN 10 KNOTS	57.8	54.1	48.6	50.0	57.7	59.1	87.5	PERCENT

TABLE NUMBER 6 : MAXIMUM SUSTAINED SPEED FORECASTS

LEAD TIME	6	12	18	24	30	36	42	HOURS
SAMPLE SIZE	588	588	588	588	588	588	299	NUMBER
MEAN ERROR	5.9	5.9	5.7	5.5	5.5	5.4	4.9	KNOTS
MEAN ABSOLUTE ERROR	7.9	8.5	8.5	8.9	9.3	9.4	9.5	KNOTS
MEAN RMS ERROR	10.3	11.1	11.0	11.4	11.9	12.0	11.9	KNOTS
UNDERFORECASTS	19.9	22.1	23.0	24.1	25.9	27.4	29.1	PERCENT
MEAN UNDERFORCASTS	5.0	5.9	6.2	6.9	7.3	7.3	7.9	KNOTS
LARGEST UNDERFORECAST	18	28	23	33	40	39	25	KNOTS
OVERFORECASTS	75.5	73.8	72.6	70.4	69.0	67.9	66.6	PERCENT
MEAN OVERFORCASTS	9.1	9.7	9.8	10.2	10.7	10.9	10.9	KNOTS
LARGEST OVERFORCAST	49	43	43	43	39	41	35	KNOTS
% WITHIN 5 KNOTS	45.9	44.0	42.2	41.0	38.8	36.4	36.5	PERCENT
% WITHIN 10 KNOTS	71.8	70.2	68.7	65.3	62.8	63.1	60.9	PERCENT

NORDCO LTD.
ENVIRONMENTAL FORECAST CENTRE

Table 4

Statistical Summary of Maximum Wind Speed in Storm Events

WELL HEAD : NAUTILUS C92
VESSEL : SEDCO 706
LAT/LONG : 46.9N 48.7W
PERIOD : SEP 24 1981 - JUL 16 1982

TABLE NUMBER 7 : MAXIMUM SUSTAINED SPEED FORECASTS OF STORM FORCE

LEAD TIME	6	12	18	24	30	36	42	HOURS
SAMPLE SIZE	100	88	80	79	78	77	36	NUMBER
MEAN ERROR	12.4	12.3	11.5	11.7	12.5	12.4	11.7	KNOTS
MEAN ABSOLUTE ERROR	13.4	13.9	13.8	13.5	14.8	14.7	14.1	KNOTS
MEAN RMS ERROR	16.3	17.0	16.5	16.6	17.8	17.4	16.5	KNOTS
UNDERFORECASTS	9.0	11.4	13.8	10.1	11.5	13.0	11.1	PERCENT
MEAN UNDERFORCASTS	5.2	7.3	8.1	9.0	10.0	8.8	11.0	KNOTS
LARGEST UNDERFORECAST	15	23	23	23	28	23	23	KNOTS
OVERFORECASTS	90.0	86.4	85.0	84.8	87.2	87.0	86.1	PERCENT
MEAN OVERFORCASTS	14.4	15.1	14.9	14.8	15.7	15.6	15.0	KNOTS
LARGEST OVERFORCAST	49	43	43	43	39	41	35	KNOTS
% WITHIN 5 KNOTS	24.0	22.7	23.8	27.8	21.8	15.6	11.1	PERCENT
% WITHIN 10 KNOTS	43.0	46.6	43.7	46.8	41.0	40.3	44.4	PERCENT

TABLE NUMBER 8 : MAXIMUM SUSTAINED SPEED FORECASTS OF 60 KNOTS OR MORE

LEAD TIME	6	12	18	24	30	36	42	HOURS
SAMPLE SIZE	47	41	37	30	29	24	8	NUMBER
MEAN ERROR	18.5	18.2	16.9	17.2	16.4	15.5	14.3	KNOTS
MEAN ABSOLUTE ERROR	18.5	18.6	17.3	17.7	17.7	17.4	14.3	KNOTS
MEAN RMS ERROR	20.9	20.9	19.3	20.0	19.7	19.5	15.3	KNOTS
UNDERFORECASTS	0.0	2.4	2.7	3.3	3.4	8.3	0.0	PERCENT
MEAN UNDERFORCASTS	0.0	8.0	8.0	8.0	18.0	11.5	0.0	KNOTS
LARGEST UNDERFORECAST	0	8	8	8	18	18	0	KNOTS
OVERFORECASTS	100.0	97.6	97.3	96.7	96.6	91.7	100.0	PERCENT
MEAN OVERFORCASTS	18.5	18.8	17.6	18.0	17.7	17.9	14.3	KNOTS
LARGEST OVERFORCAST	49	43	43	43	37	41	24	KNOTS
% WITHIN 5 KNOTS	12.8	7.3	8.1	6.7	6.9	4.2	0.0	PERCENT
% WITHIN 10 KNOTS	17.0	22.0	21.6	26.7	20.7	20.8	25.0	PERCENT

NORDCO LTD.
ENVIRONMENTAL FORECAST CENTRE

Table 5

Statistical Summary of Combined Wave Heights in Severe Events

WELL HEAD : NAUTILUS C92
VESSEL : SEDCO 706
LAT/LONG : 46.9N 48.7W
PERIOD : SEP 24 1981 - JUL 16 1982

TABLE NUMBER 15 : COMBINED WAVE SIGNIFICANT HEIGHT FORECASTS FROM 4.9 TO 7.9 METRES

LEAD TIME	6	12	18	24	30	36	42	HOURS
SAMPLE SIZE	80	86	71	66	65	67	33	NUMBER
MEAN ERROR	1.6	1.8	1.7	1.8	2.3	2.8	2.9	HALF METRES
MEAN ABSOLUTE ERROR	2.5	3.0	3.1	3.2	3.5	3.9	3.8	HALF METRES
MEAN RMS ERROR	3.1	3.5	3.8	3.9	4.2	4.5	4.6	HALF METRES
UNDERFORECASTS	17.5	22.1	26.8	21.2	21.5	17.9	18.2	PERCENT
MEAN UNDERFORCASTS	2.6	2.7	2.7	3.3	2.9	3.1	2.3	HALF METRES
LARGEST UNDERFORECAST	7	6	9	9	6	7	4	HALF METRES
OVERFORECASTS	70.0	67.4	64.8	68.2	70.8	71.6	66.7	PERCENT
MEAN OVERFORCASTS	2.9	3.5	3.7	3.6	4.1	4.7	5.0	HALF METRES
LARGEST OVERFORCAST	7	8	9	9	9	9	10	HALF METRES
% WITHIN 1 METRE	56.2	46.5	43.7	45.5	36.9	26.9	30.3	PERCENT
% WITHIN 2 METRES	83.8	73.3	74.6	69.7	60.0	55.2	57.6	PERCENT

TABLE NUMBER 16 : COMBINED WAVE SIGNIFICANT HEIGHT FORECASTS OF 8 METRES OR MORE

LEAD TIME	6	12	18	24	30	36	42	HOURS
SAMPLE SIZE	8	8	9	9	7	7	3	NUMBER
MEAN ERROR	2.5	6.9	8.0	8.1	6.6	4.3	4.3	HALF METRES
MEAN ABSOLUTE ERROR	3.0	6.9	8.0	8.1	6.9	4.6	4.3	HALF METRES
MEAN RMS ERROR	4.0	7.3	9.5	9.1	7.5	5.6	5.2	HALF METRES
UNDERFORECASTS	12.5	0.0	0.0	0.0	14.3	14.3	0.0	PERCENT
MEAN UNDERFORCASTS	2.0	0.0	0.0	0.0	1.0	1.0	0.0	HALF METRES
LARGEST UNDERFORECAST	2	0	0	0	1	1	0	HALF METRES
OVERFORECASTS	62.5	100.0	88.9	100.0	85.7	85.7	100.0	PERCENT
MEAN OVERFORCASTS	4.4	6.9	9.0	8.1	7.8	5.2	4.3	HALF METRES
LARGEST OVERFORCAST	8	9	21	15	11	8	8	HALF METRES
% WITHIN 1 METRE	62.5	12.5	11.1	11.1	14.3	42.9	33.3	PERCENT
% WITHIN 2 METRES	75.0	25.0	11.1	11.1	14.3	42.9	66.7	PERCENT

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8 m success falls to about 10 to 15% at 12 hours, although improves dramatically to 63% at 6 hours. These tables also show that unlike the wind forecasts wave prediction becomes increasingly more accurate as the lead time decreases. For example in the 5 to 8 m class the mean absolute error decreases from about 2 m at 36 hour lead times to about 1.3 m at 6 hours.

In comparing wave heights this way one must bear in mind that the observations are not of instrumental accuracy; MANMAR wave heights are a blend of visual swell heights and (sometimes) measured wind sea heights. They seem to be reliable in a statistical sense (e.g. Jardine, 1979) but individual values may contain large errors. One must also recognize that the statistical summary for wave heights above 8 m is based on very small sample sizes (7 to 9 observations) and as a result the frequency and error values have low confidence.

The values discussed above for NORDCO, and previously for AES (NWO), are <u>indicative</u> of verification procedures, and the nature of marine forecast accuracy. They are not presented as measures of how well either agency does at forecasting in an absolute sense. It would not be appropriate to draw this type of conclusion from the information discussed here because the cases examined are too few and too confined geographically.

5.2.3 New Case Studies

Seven severe storms from the 1981/82 winter season over the Grand Banks have been selected to examine forecast performance in time series format. The following data have been used for comparison purposes:

Forecasts

AES - Newfoundland Weather Office: for the Northern Grand Banks, issued every 3 hours (wind speed and direction only),

NORDCO - for specific rigs in the Hibernia area, issued every 6 hours (6-hour mean wind and direction only),

METOC - for specific Waverider locations on the Northern Grand Banks near Hibernia, issued every 12 hours (wave height only).

Observations

MANMAR - rig data pertinent to the forecast location (wind speed and direction only),

Waverider data - at the rigs "Ocean Ranger," "Sedco 706," and "Zapata Scotian" (significant wave height only).

The time series plots are presented in Figures 9 to 15: in each graph the prognoses are shown as discrete symbols for 12, 24 and 36-hour lead times. This reflects the fact that the prognoses represent average, or "expected," conditions over the valid periods (e.g. 6 hours for NORDCO) and not smoothly varying continuous functions. The METOC "analysis" lines have been added to each graph for H_s -- these represent the time-zero sea state conditions as analyzed by METOC using past chart data and actual observations. All METOC data plotted here have been read directly off the charts at the Waverider location, and have a precision of ±0.1 m.

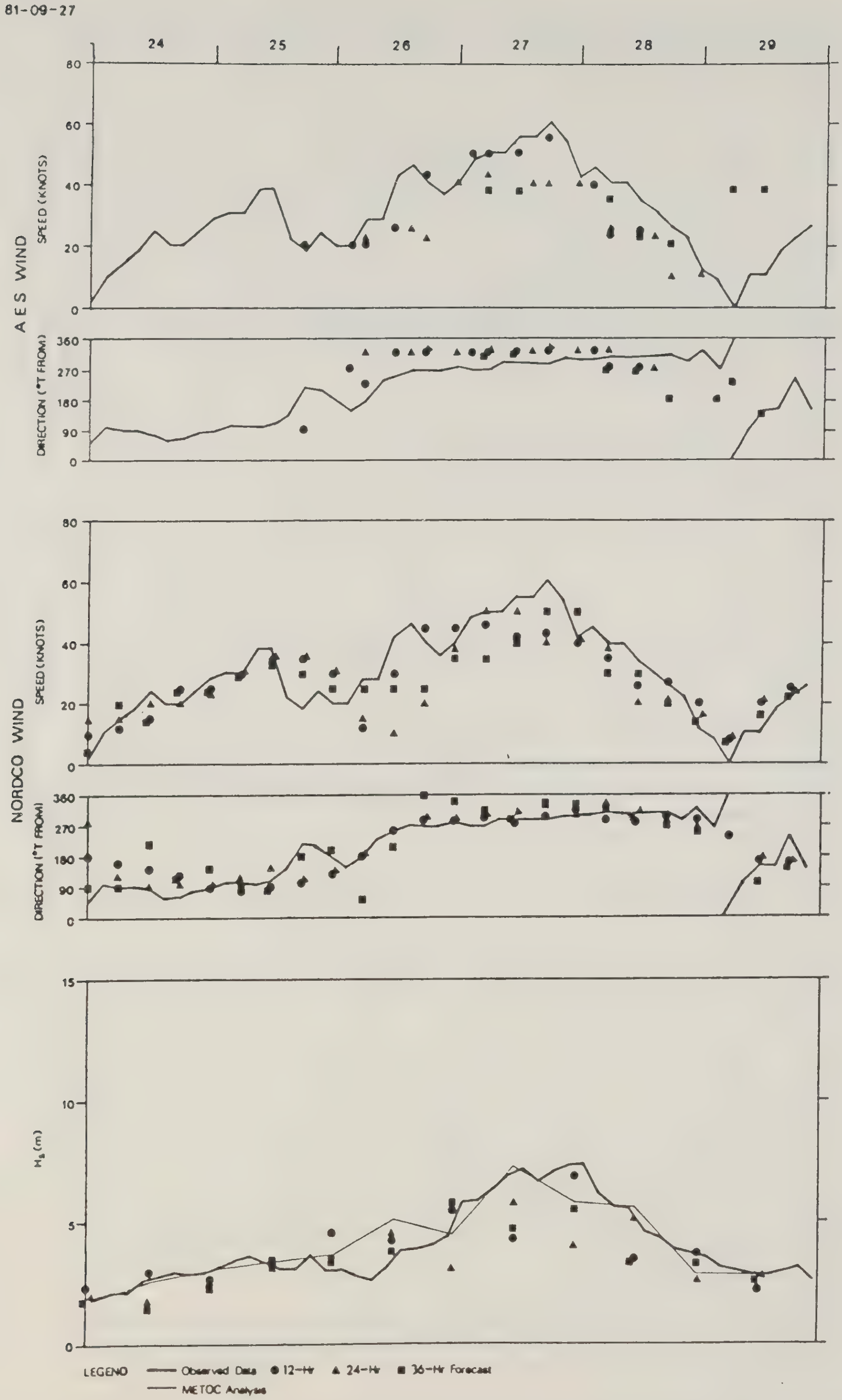

Figure 9 Comparison of predicted with measured winds and waves for the storm of September 27, 1981.

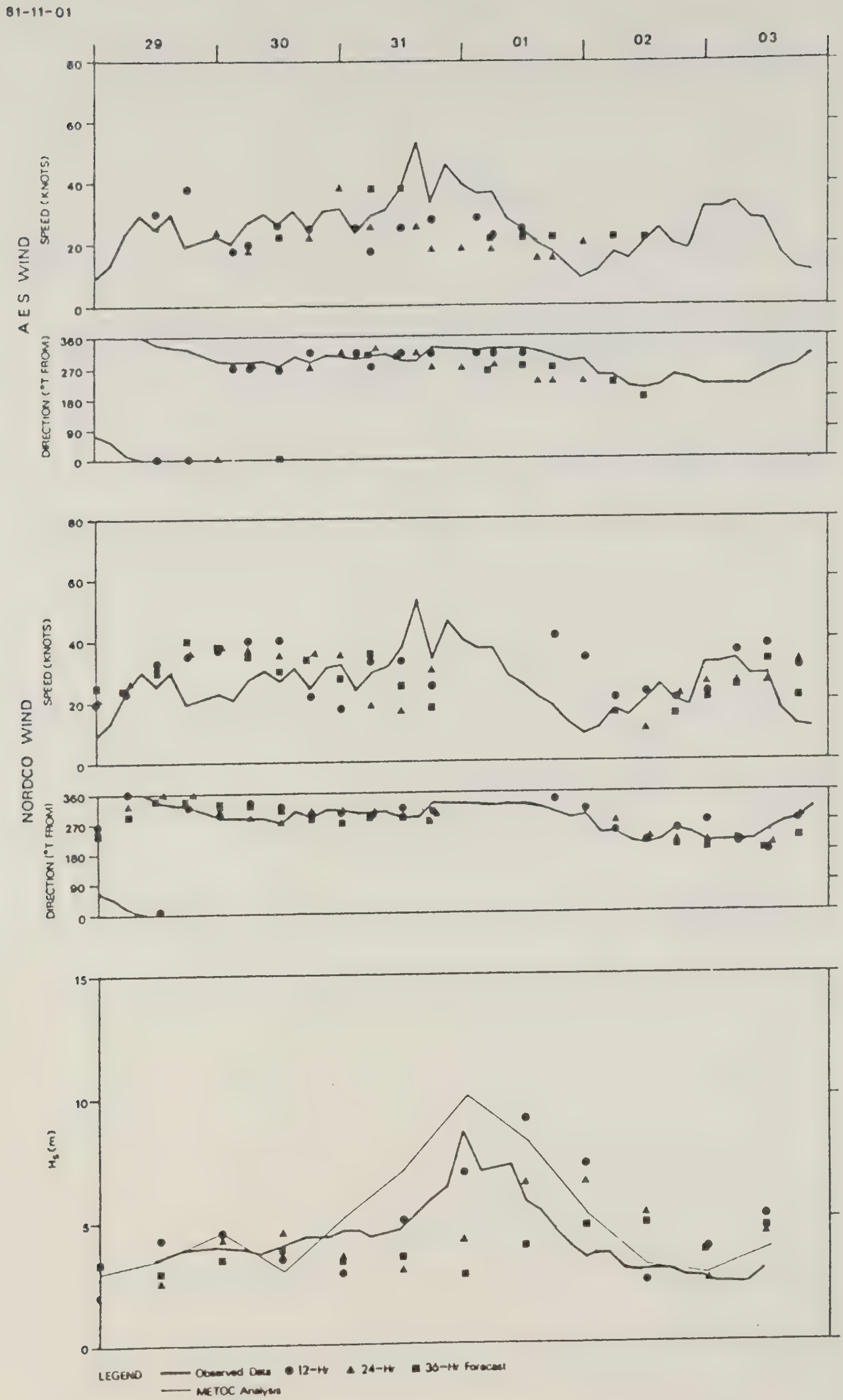

Figure 10 Comparison of predicted with measured winds and wave for the storm of November 1, 1981.

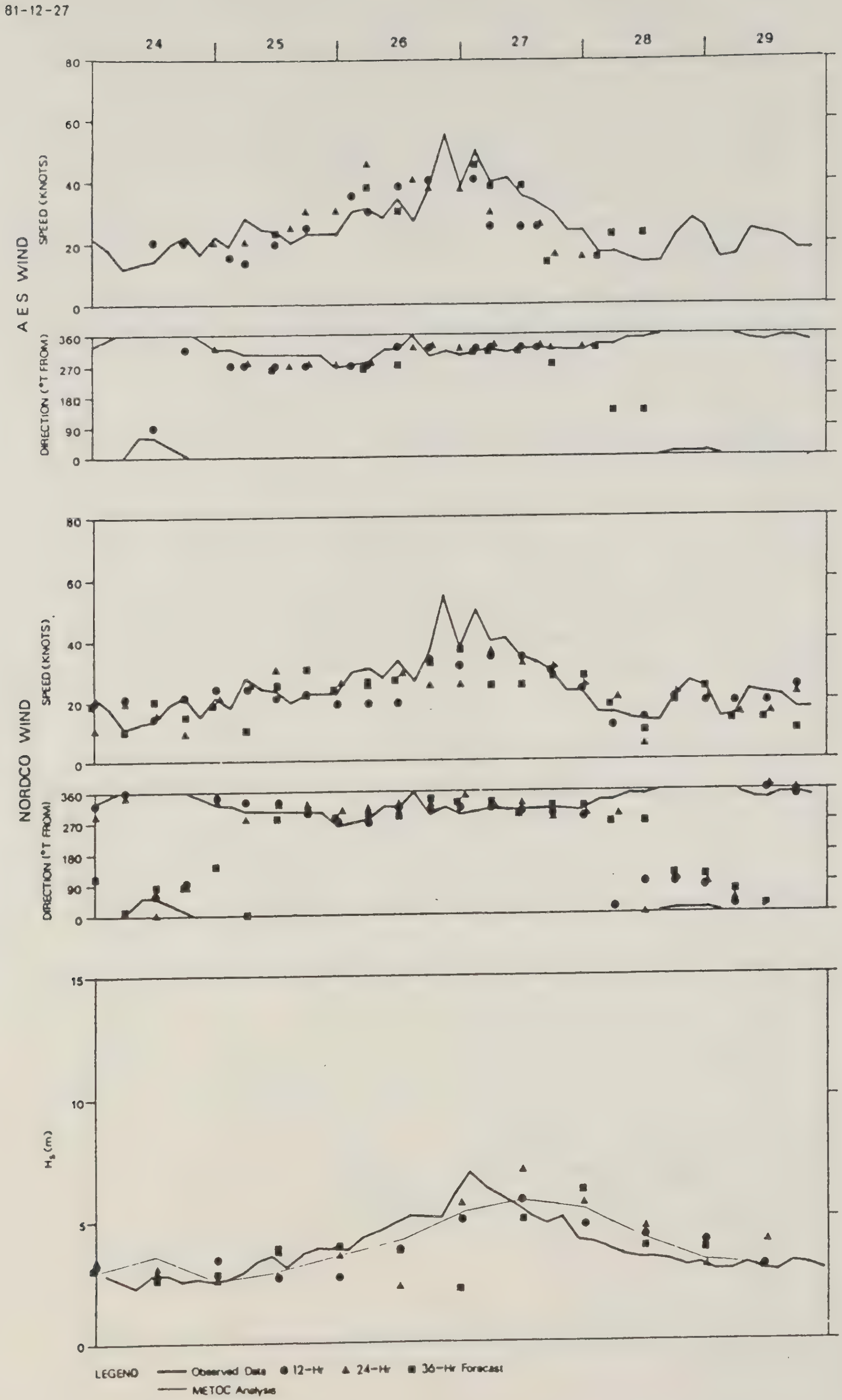

Figure 11 Comparison of predicted with measured winds and waves for the storm of December 27, 1981.

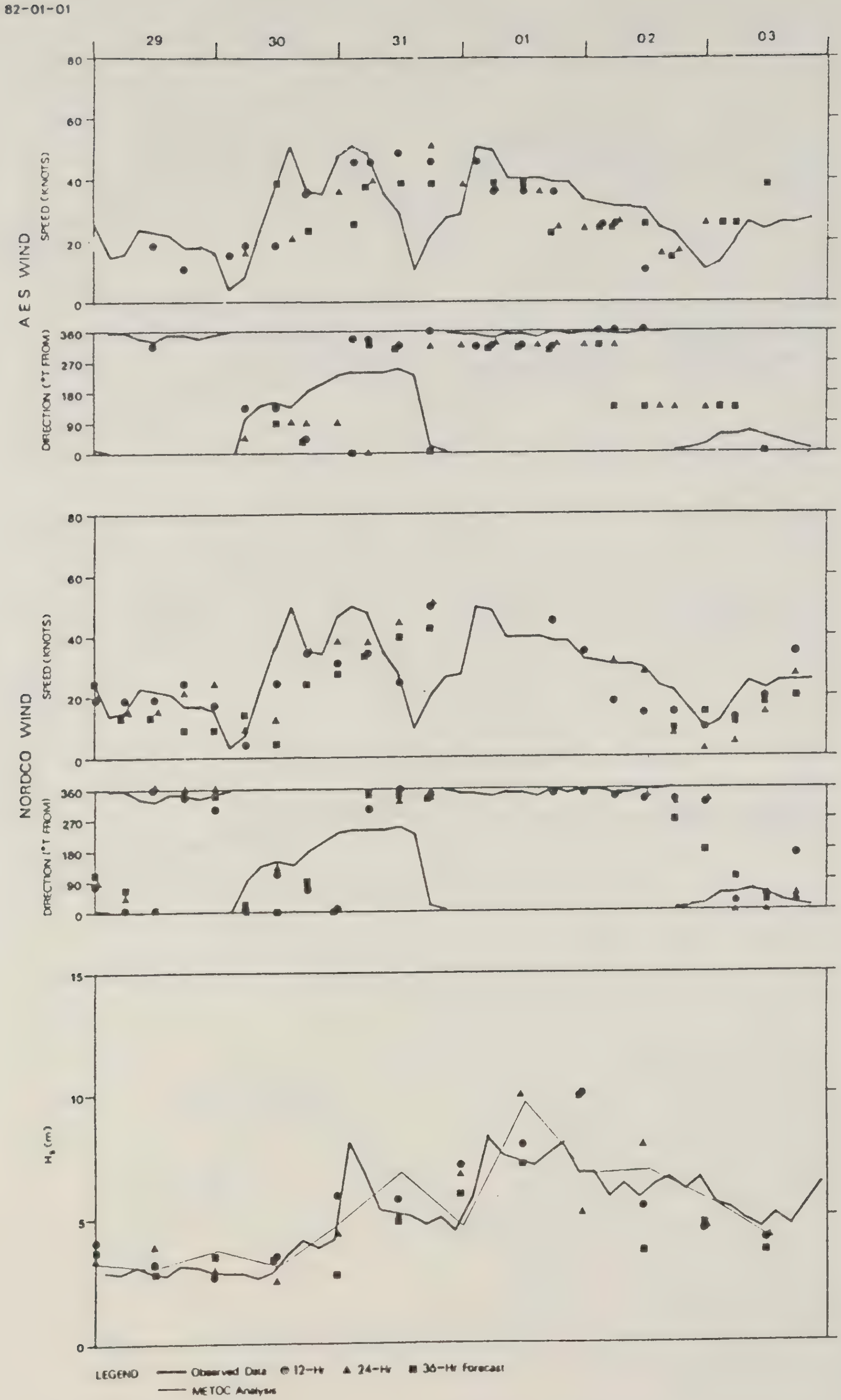

Figure 12 Comparison of predicted with measured winds and waves for the storm of January 1, 1982.

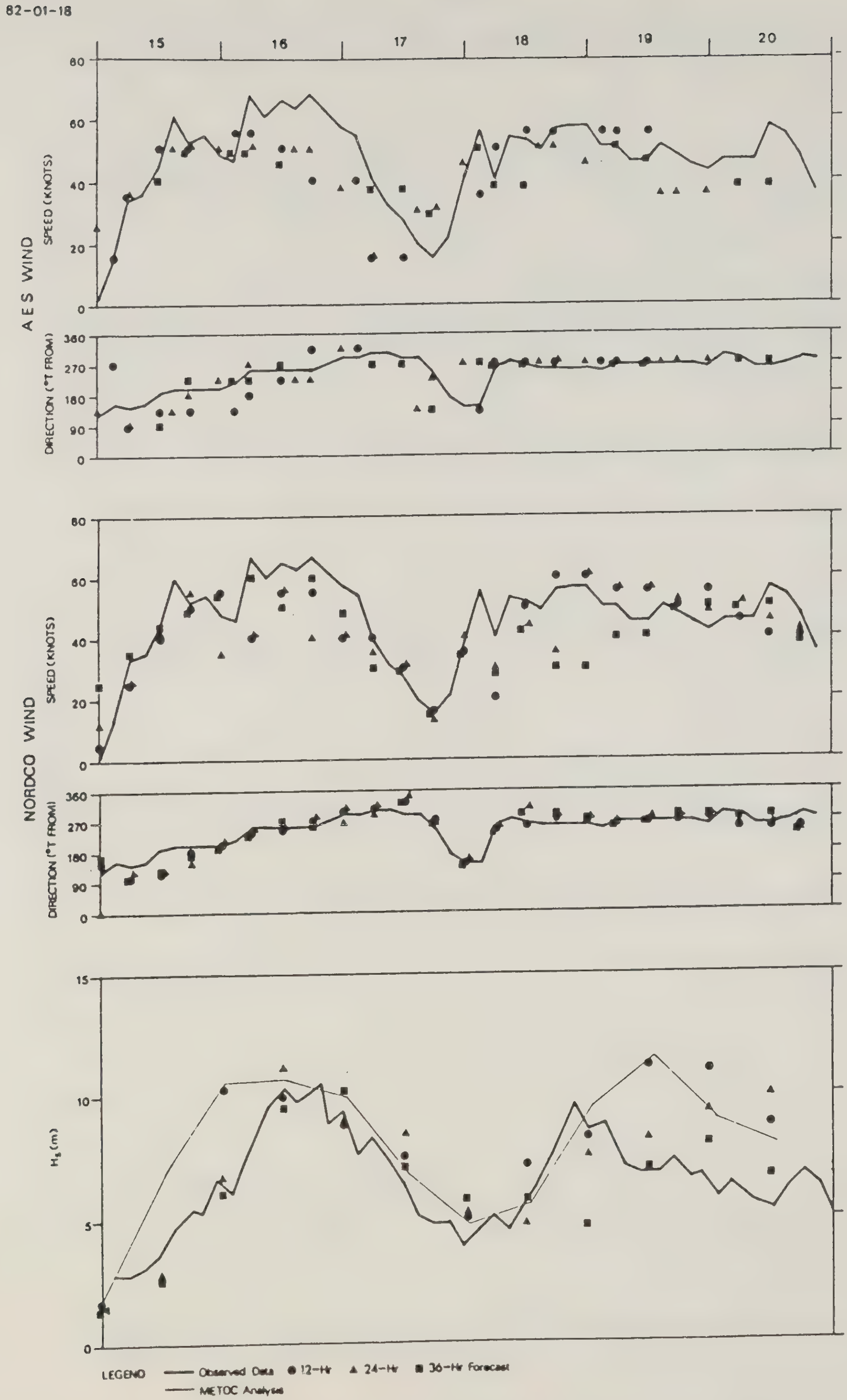

Figure 13 Comparison of predicted with measured winds and waves for the storm of January 18, 1982.

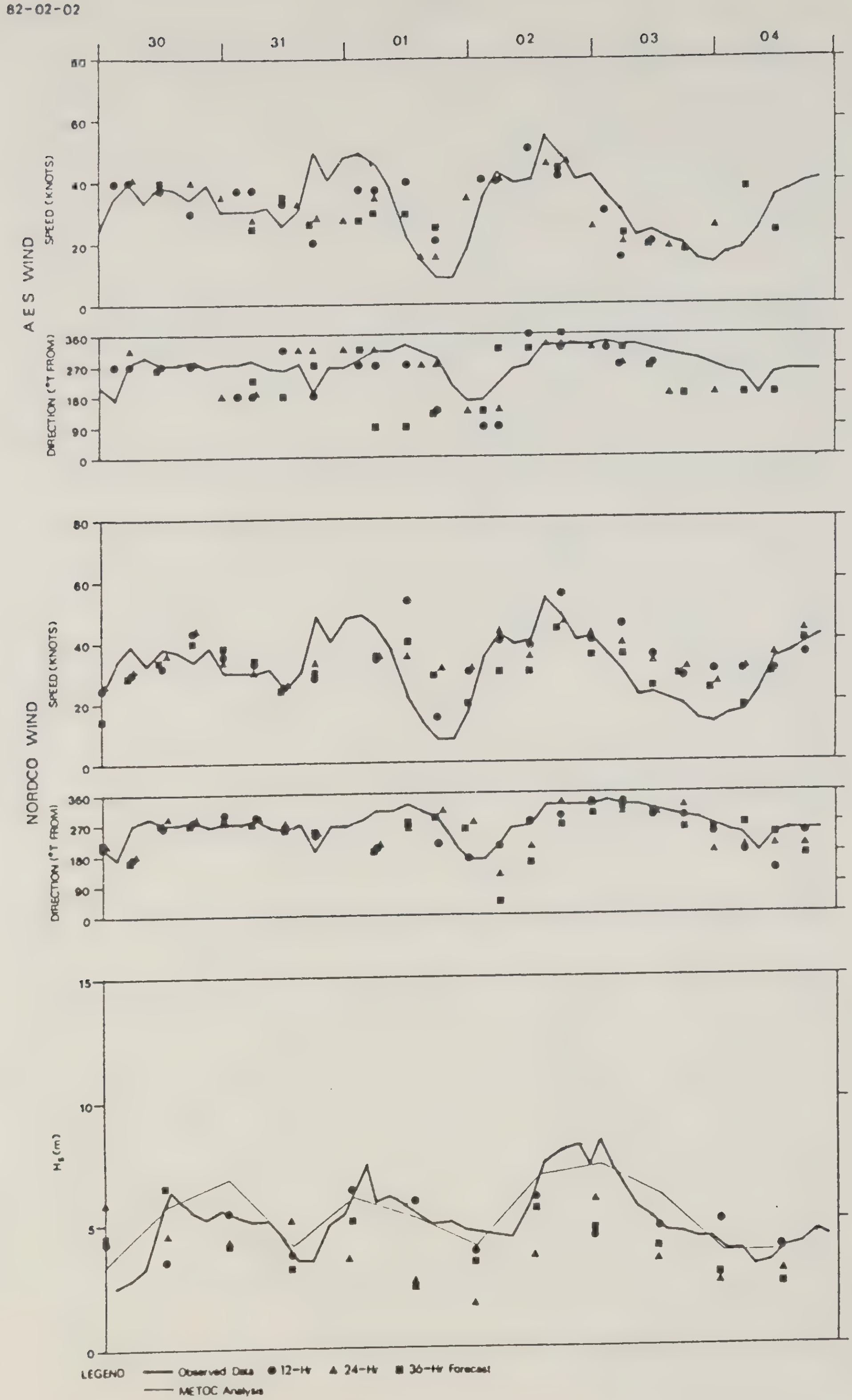

Figure 14 Comparison of predicted with measured winds and waves for the storm of February 2, 1982.

82-02-14

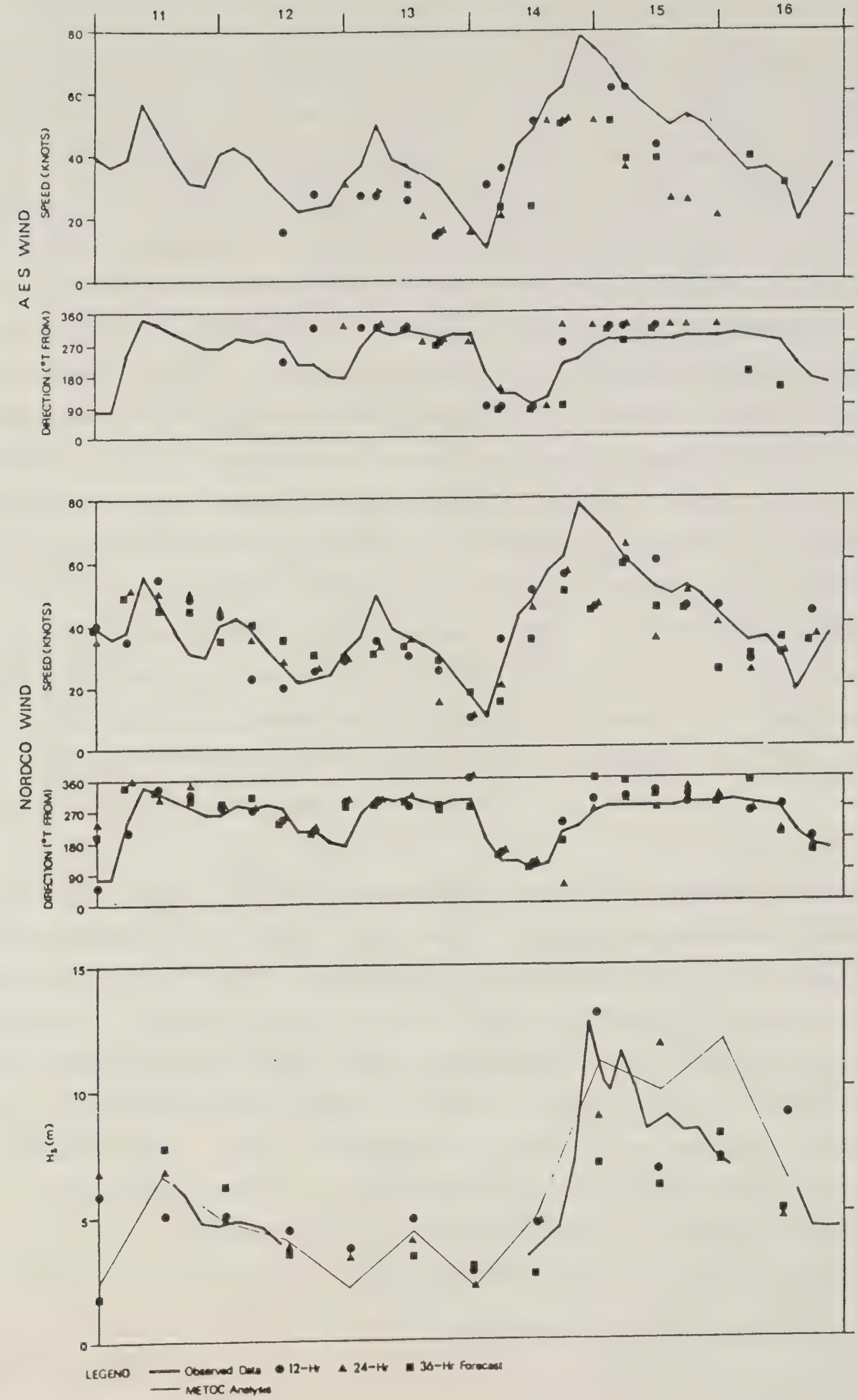

Figure 15 Comparison of predicted with measured winds and waves for the storm of February 14, 1982.

In general the AES winds tend to underestimate the peak storm winds, and on occasion (Dec. 31, 1982, Figure 12) get the timing wrong also. This is true of the NORDCO forecasts as well which tend to follow the trends found in the AES prognoses. However, underprediction by the NORDCO mean wind is expected since the comparison is made here between a predicted 6-hour mean and a one-hour mean measured wind. When the mean wind underpredicts, NORDCO's "maximum wind" parameter provides a better fit to observations; e.g. they predicted maximum speeds of 75 to 80 knots at the peak of the Feb. 14-15, 1984 storm (Figure 15) with observed winds of about 78 knots. There was, however, a timing error of about 12 hours with predictions lagging the peak observation (for the 12-hour forecast; the 6-hour prediction was much closer to observed conditions). Conversely when the mean wind agrees with the observations (Feb. 2, 1984, Figure 14) the maximum wind will be too large.

There is considerable variability in forecast accuracy as a function of lead time and it is impossible to make a general statement on this from the data portrayed here. NORDCO (1983) have shown statistically that accuracy improves as the lead time decreases, i.e. 6-hour prognoses are more accurate more often than are 24 and 36-hour predictions. The scatter in the predictions about the observation lines in Figures 9 to 15 reflects the difficulties of predicting the individual storms in this small sample, differences in forecaster skill and differences in the quality of data available on each storm as it developed.

The METOC H_s-predictions evidently capture the major variations in the wave height fields, but as with wind there is a wide scatter in predictions for different storms and for different lead times (see e.g. the storms

of Jan. 18-20, 1982 [Figure 13] and Feb. 15, 1982 [Figure 15]).

From these graphs one can see that forecasting accuracy is highly variable and that the predicted wind speeds and directions, and wave heights, do not reflect the accuracy normally associated with instrumental readings. Stated another way, one can not expect to receive and use predicted parameters at a given point in time as if they were punctual measurements; the uncertainty is very much greater. This point may seem obvious to those involved in forecasting practice but is worth stating clearly for those who are not. The main purpose of the preceeding graphs is to illustrate the nature of forecast variability. Statistical assessments of accuracy are presented in much more detail in, for example, NORDCO's verification reports.

The principal shortcoming of these statistical summaries is, however, the loss of any sense of timing accuracy. Differences between predicted and measured wind parameters may, for example, be due to wrongly estimating the timing of the weather system's impact on a given area as to incorrectly "modelling" the system's development in terms of physical processes (deepening of lows, motion of fronts and so on). In this regard the time series format is particularly valuable.

5.3 Discussion of Procedures

Verification procedures used by forecast agencies and aimed at establishing the absolute accuracy of forecast weather parameters, examined in this study, are based on comparing site-specific data pairs, consisting of the predicted variable and the synchronous observation, over several months of service. These pairs are analyzed

statistically to give measures of error in the forecasts; in some cases this is done over the entire range of values for a given parameter, or on stratified samples for selected subranges (e.g. wind speed for storm force winds). These procedures provide tables of statistics which give an overall indication of forecast performance. They do not, however, indicate why and how large errors occur, particularly at the high end of severe events and do not illustrate how often the timing of forecasted severe weather has been correct or not even if the magnitude has been close.

Also they have been applied only to wind speed and direction, and wave height and period parameters. Predictions of the occurrence of fog, heavy rain or snow, and freezing rain as these may affect aircraft and ship operations are not generally verified at all.

Event-by-event verification in time series format is not used in any routine or formal way at present. This is unfortunate because it shows how both magnitude and timing errors affect forecast accuracy. Treating the data as time series also allows one to use more advanced processing techniques to correlate the predicted and measured signals, thereby quantify magnitude and phase errors. The obvious limitation in this approach is that it reduces a complex three dimensional physical process to a one dimensional response signal at a single point.

6. METEOROLOGIST STAFFING

It is clear that presenting accurate site and area-specific weather forecasts requires well trained and locally experienced personnel. Given the size and redundancy of the government and private forecasting services in Canada, competition for good staff arises, and to some degree this must affect the quality of forecasts issued to offshore drilling units.

Meteorologists hired by the AES are usually graduates of one of the several Canadian universities that offer a degree course in meteorology. After recruitment, a substantial course in operational meteorology is provided by the Service in Toronto. In early assignments a meteorologist will usually serve two year periods in both civilian and Canadian Forces offices to ensure career flexibility. After these initial assignments a meteorologist will tend to settle into one office for a number of years in order to develop regional experience, also viewed as an important part of career development.

The meteorologists hired by private companies are usually graduates of Canadian universities and some have had AES training and experience as well. Foreign-trained meteorologists, most often British, and usually with resource development experience in the North Sea or the Near East, are another source. In the industry guidelines (COGLA, 1983) it is stated that meteorologists employed privately "should meet AES standards for training and experience and at least half of the forecasters should have substantial experience with AES core guidance material." Also the forecast team should have some professional forecast experience in the geographic region.

Since AES is quite competitive in the job market, it is

difficult for private firms to attract experienced AES forecasters into "shift-watch" positions. This is due in part to better remuneration and job security in AES, and in part to perceived career development. Another difficulty is that meteorologists recruited from abroad are needed in the work place when they arrive, and it is difficult for them to obtain direct training in AES methods.

While the private companies in the Atlantic Region experience difficulty in attracting and holding sufficient numbers of experienced meteorologists AES also has some problems. Because NWO is located at Gander for reasons associated with the development of meteorology during World War II, and this is a relatively isolated community, few of the professionals assigned there stay much longer than the required two year initial assignment. As a result of this and because initial contact training periods there tend to be longer than normal due to the varied and often difficult weather patterns encountered in the area, strains are placed upon the professional resources of the office.

While one can appreciate and describe staffing difficulties it is impossible to gauge what effect these have on forecast accuracy and performance. One reason for this is that each of the agencies approaches its job slightly differently and there are no universal standards or formats for forecast presentation and verification. Thus there is no objective basis upon which to form an assessment.

7. CONCLUSIONS

7.1 Some Opening Remarks

Both parts of this report have emphasized the large, and in many ways redundant, organization of forecast services in Canada. We have also found that all of the agencies involved are tightly linked, especially at the level of regional weather offices (AES) and private forecast firms, because they base prognoses on the same cascade of information from within the organization, and approach weather forecasting using the same meteorological principles and equipment. Indeed this is a position largely demanded by the bodies that regulate offshore drilling programs.

One consequence of this parallelism in private and public forecasting groups is a profound similarity in the preparation and presentation of forecast material. For reasons based on the sparcity of observing points over the ocean and incomplete understanding of atmospheric physics, these forecasts deal with changes in weather on synoptic scales, over distances exceeding 200 to 300 km and durations of 2 to 3 days. Smaller mesoscale events, often producing the most severe, if short-lived conditions, are not encompassed in the preparation methods. Hence they cannot be reflected in the forecasted parameters. Thus a user of forecast data must clearly understand what the parameters do, or do not, mean. Because of the similarity in forecasts noted above, there are no significantly different alternative presentations to guide users.

This is not to say that the presentations look the same. The private forecast firms supplying information to offshore operators, in particular, have adopted rather scientific formats for presenting wind and sea state

parameters as a function of lead time in 6-hour increments. In view of the precision implied by this type of presentation it is tempting to interpret these data as measures that will be realized as storms pass over a given area or location; it is tempting to ascribe an "observational" accuracy to them, to treat them like design criteria.

But as agency verifications, and time series comparisons in this study show, forecasts of severe weather are successful about one half or less of the time when judged by accuracy standards expected of measurements. Thus any attempt to <u>use</u> forecasts to make decisions controlling offshore operations <u>must</u> take the uncertainty into account. These uncertainties appear much larger than engineers would normally accept (or expect) of design and operational criteria; consequently, to view forecast parameters like criteria and thereby relate them to the behaviour of a rig, a vessel, a downhole operation, or an aircraft at a given point in time would be a misuse of the data. One result of doing so may well be a threat to human safety on one hand, or a very expensive loss of drilling time on the other.

This raises the issue of the relevance of forecast information, as it is currently presented to and used by offshore operators. And this in turn, leads to the criterion by which one can judge forecast adequacy.

7.2 The Essential Criterion for Assessing Adequacy

The principal goal of this study was an assessment of the adequacy of marine weather forecasts for offshore exploratory drilling practice. The only criterion by which to judge this adequacy is to determine whether or not the data are adequate for proper decision making by

the end-user groups, and whether or not the decision-making process meets some acceptable standard for ensuring offshore safety. To do this would require a study of how the data are actually used within each operator's organization: how the data are perceived or interpreted for the uncertainty in them, whether the parameters as received are the correct ones, what the consequences are of errors in the forecast data, and what decision making procedures are currently in place. In short, one would seek to establish the amount of relevant information in forecast data and weigh this against decision-making requirements.

However, the mandate of the present study did not extend to the practices of the offshore operators, either on the rigs or in their central coordinating offices. Thus it is not possible, in our view, to reach conclusions on forecast adequacy in a kind of absolute sense at this time. The discussion to follow attempts, then, to present conclusions and points for consideration useful to the next step in such an assessment of adequacy.

7.3 Conclusions on Weather Forecasting Practice

7.3.1 On Content

As discussed above simple meteorological and sea state parameters presently form the basis of forecast data. These are parameters nearly everyone is familiar with from public weather broadcasts: wind speed and direction, sea wave heights and periods, temperature, pressure, visibility, and freezing spray. They are presented in descriptive and/or numeric terms to cover an area or a point in the ocean, at regular increments of time -- the valid periods -- usually 6 or 12 hours apart. Given the complex spatial structure (multiplicity of scales) and

dynamic aspects of storm systems, and the intended uses for the data, two questions must be addressed:

1) do these parameters provide sufficient information on weather for the user? and

2) are these the relevant parameters for the intended user?

The first question deals with the information level of forecasts: when one considers how much prognostic data have been distilled (predictive atmospheric and wave modelling) to produce the parametric forecast, they contain a very low level of information. This statement is reinforced by the fact that forecasts issued every 6 hours deal only with synoptic scale systems, omitting smaller, more rapid components that should in principle be reflected in the parameter lists.

Two examples will illustrate the concept. The safety of low-level aircraft operations is threatened by sudden changes in otherwise good flying weather, either by squalls, heavy precipitation in rain bands, or fog. This can be particularly dangerous at the rig, where even flow modification of gusty winds by the structure itself can increase the hazard. A forecast which doesn't prepare personnel in the aircraft or on the vessel for such occurrences of severely deteriorated conditions contains far less information than one that does. Since flying times offshore, and decisions affecting airborne operations, last a few hours to a few minutes, 6-hourly forecasts using one value of each parameter to cover a large oceanic area provide only the most basic average appraisal of conditions to be expected enroute; in no way can they prepare pilots for perturbations about this average which are likely to pose the danger. This has, of

course, been recognized for many years and is why the airways forecasts are given on as nearly a continuous basis as deemed necessary. They also attempt to include guidance on conditions near fronts but, like the standard marine forecasts, are constrained in this by the synoptic-scale focus of the prognoses from CMC and AWC.

Sea state parameters are usually specified (and observed in MANMAR procedures) as a wind sea and two swell (primary and secondary) components. These are added up to give a "combined" sea wave height, period, and direction. There are no parametric hindcast procedures which truly model the physics of old swell seas, and to date, large-scale discrete spectral wave models, which would approximate the propagation of swell components, are not used in Canada for wave forecasting. Therefore the two forecasted swell components are largely meaningless and about the best one can do is interpret the combined sea height as roughly equivalent to a significant wave height averaged over the valid time of the forecast. Thus the forecast contains one wave height and period, and a rough indicator of direction (the maximum wave height is just a statistical extrapolation of the first value and does not increase the information contained in the forecast), to represent a given location at sea. It is updated every 6 hours. During a storm these are, for example, the minimum data requirements for assesssing the expected motion of a floating drilling vessel. A more reliable motion analysis would obtain from predicted wave spectra computed with two-dimensional models on a one-hour time step. Such spectra would resolve crossing seas and rapid changes in wave growth as the storms peak over specific locations. Thus the presentation of spectra, properly computed, as opposed to wave height and period would provide a significant increase in the information contained in sea state forecasts.

To be effective, forecasts that deal with mesoscale atmospheric processes and wave spectra, as two examples, involve fundamental changes to present data acquisition and presentation techniques. These will be discussed in the next section.

The second question -- on relevant parameters -- is vitally important. To be of any use the forecast information must provide the decision maker with exactly what he needs to take a certain action. Without rather detailed consultation with offshore operators their data requirements cannot be specified here, but a number of questions can be put forward to illustrate how these might be determined:

1) What parameters require what lead times? - for example, wave height or rig heave estimates out to 48 hours might suffice for scheduling a downhole operation, but wave spectra or detailed vessel motions may be required with 6, 5, 4, 3, 2 and 1-hour lead times to order rig evacuation during a storm.

2) What parameters are really required? - for emergency evacuation, are spectra of any use at all or does the operator really require rig motion estimates? - for resupply, are spectra or wave heights of any use or are supply boat pitch and heave or crane derating values really required? - for aircraft operations, is the 6-hour mean wind of any use or does one need gust speeds or expected gust spectra along the flight path or at the rig.

3) How should forecast uncertainty be portrayed in the predicted parameters? - how would the operator use it if it were?

The "response" parameters indicated above are all derived

from meteorological parameters through mathematical models, which while introducing some additional uncertainty into the predictions, may improve the relevance. We emphasize the importance of establishing parameters for marine forecasts that are directly useful to the drilling operators. There has been a tendency to direct resources at upgrading traditional forecasting procedures and data products, especially with the use of very large computers, and while this may lead to increased information levels in traditional forecasts, if they are not relevant to the intended user there has been no net gain.

7.3.2 On Presentation

Forecasts are presented in a very rudimentary manner with all parameters given equally for the same lead times, and transmitted over telecopier circuits or broadcast. Where users receive analysis charts and satellite imagery over photo-facsimile machines prognoses can be supplemented with current information on the spatial structure of weather systems. While it is not possible to judge presentation adequacy independently of the issues raised above, the absence of colour graphics displays showing two-dimensional prognoses blended with observational data (satellites and weather radar images, for example) is unexpected. It would be possible, given present-day transmission capabilities, to show the dynamic behaviour of storm systems, in the past and projected into the future, to isolate and predict some small scale events within them, and to present both area and site-specific forecasts rapidly and interchangeably. This would allow, for example, short lead-time prognoses with detailed information to be sequenced with longer lead-time less detailed presentations.

Because this implies complete computerizaton of forecast

dissemination, incorporating auxilliary models to translate meteorological parameters into, perhaps, more relevant outputs (e.g. vessel response) would be straightforward.

7.3.3 On Verification

Verification of marine forecasts given by private firms is well established and is now providing a great deal of information about forecast quality. It tends, however, to be statistical and to remove the connection between storm history and the nature of errors in severe events. Verification of forecast performance using time series analysis techniques to show the relationship between magnitude and timing errors would also be of value. Useful, too, would be an anlaysis of the consequences of various kinds of missed events, e.g. the storm peak predicted too early or too late by several hours, on offshore operations.

Because forecasting is based upon manipulation of observed or forecast synoptic weather systems, post-mortem analyses of particularly difficult events, together with a formal mechanism to transfer the experience so gained to all forecast personnel, would be valuable and must receive more attention. The intent should be to improve procedures and "build in" this information.

7.4 Closing Statements

Weather forecasting represents an attempt to predict the behaviour of, arguably, the most complex fluid dynamic system in nature. That it enjoys some measure of success is a tribute to the knowledge that has been accumulated over the years, and the functioning of the combined services presently doing routine forecasting. Through

guidelines put in place by regulatory bodies, private forecast firms carry a large measure of responsibility for providing weather information to offshore operators. While closely tied into the Atmospheric Environment Service for data acquisition, by standards of training, and by a common philosophy to predicting weather, they function independently in dealing with operators. Thus it is possible to examine their performance relative to the AES.

We have found that, after a preliminary study of NORDCO, it does not appear that one organization, AES or private company, consistently outperforms the other. There is no basis to claim that provision of forecast services by private firms to the offshore is inadequate, relative to standards that could be established for AES itself. Both organizations appear to be presenting much the same quality of forecast information using very similar parameters. We also note that it is difficult to generalize this conclusion because there are few verification data available for AES and the other private firms.

However, we find that forecasts actually contain a very low level of information, due in part to the traditional approaches used in government forecast services for presentation, in part to sparseness of data collection points at sea, and in part to limitations of present knowledge about atmospheric physics. Forecasts provide data on changes in weather that cycle in periods of days but little or no information on short term events lasting a few hours. They provide numerical values for parameters like wind speed and wave height that appear individually to have a high precision, but statistically have low reliability. (Stated another way, forecasting tends to predict the major trends in weather correctly, but

achieves low accuracy on any one value in the sequence.) For these reasons, among others discussed above, it is not clear that the forecast parameters are necessarily the most relevant ones for offshore operators.

At this point we believe, therefore, that to make any rational assessment of the adequacy of present forecasting services, it is necessary to step back from this examination of the forecasting side, and look at the entire relationship between regulatory expectations for offshore safety, industry needs to meet these and other operational demands, and the ability of forecasting groups to satisfy these needs. Offshore operators must carefully consider how they would use forecast data to reach decisions affecting human safety at sea, and in doing so decide exactly what data are needed and in what forms. Having done this it can be judged whether present forecasting methods can provide the necessary information or whether fundamental changes are needed.

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